

EFFECTS OF WHEAT CROP ROTATION ON
RICE (Oryza sativa L.) SEEDLING GROWTH

By

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With love and thanks, I dedicate this dissertation to my parents
Raynal and Chuck whose patience, love, and persistence provided the
support and self-confidence I have today.

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Abstract of Dissertation Presented to the Graduate School
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EFFECTS OF SOIL CROP STRIDGES ON
RICE (Oryza sativa L.) GROWTH DYNAMICS

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Rice (Oryza sativa L.) ratooning is an established method to increase rice production and reduce costs per unit land area. While main crop rice biology has been extensively studied, the effects of main crop development on ratoon crop growth dynamics have not been thoroughly investigated. The purpose of this study was to investigate the effects on main crop growth parameters and how these may have affected ratoon crop performance. Two early season rice cultivars, Gulfstream, a semi-dwarf, and Liberton, a tall cultivar, were drilled seeded on phosphatic settling pond clays in Polk County, Florida. Phosphatic clays are characterized as amorphous, carbonate-chlorapatite, allophanic, and other soil constituents which form a fertile soil environment. Five levels of urea nitrogen (0, 30, 60, 90, and 120 kg ha⁻¹) were applied basally before permanent flood to the main crop. The ratoon crop received 120 kg ha⁻¹ applied basally before permanent flood.

Main crop stubble, analysed for total structural carbohydrates (TSC), had decreased TSC levels as B value increased. Significant and positive correlation was found between early main tiller number (J4 and J5 200) and TSC concentration in the 1988 main crop stubble.

Main crop tiller number m^2 increased as main crop B value increased for both cultivars, while Labount produced more tillers than Galfiori. Main crop tiller data showed no B effect; however, Labount produced a higher tiller number than Galfiori.

Main crop particle m^3 (P6) increased as B value increased with Labount producing more particles than Galfiori. Main crop P6 data showed no B effect, and Labount confirmed the trend, producing more P6 than Galfiori. Galfiori produced more grain particle m^3 than Labount in both main and ratoon crops.

Variable plant density in 1988 resulted in variable yield data. In 1988 yields of Labount (9440 kg ha⁻¹) were greater than (P<0.01) Galfiori (8000 kg ha⁻¹). Main crop data showed no B effect for Galfiori while Labount displayed a quadratic B response. Maximum ratoon yields were 3000 kg ha⁻¹ for both cultivars. Total yield data for both cultivars exhibited a linear B effect. Total yields of Labount were greater than (P<0.01) Galfiori (7700 vs 7100 kg ha⁻¹, respectively).

INTRODUCTION

Reversing previously mined lands to a productive capacity equal to or better than their original state is the goal of agricultural research on phosphate-mined areas in central Florida. A principle ingredient of phosphate mining is phosphatic clay which has unique chemical and physical properties: high levels of smectite, carbonates-fluorapatite, and allophane; predominant phosphatic clay composition; small particle diameter is 125 μ or smaller with 80% less than 1 μ in diameter (Hemond, 1982). In terms of chemical properties, pH is near neutral, and there are moderate to high levels of most elements (except N) necessary for crop production (Schmidt et al., 1982). Utilization of phosphatic clays for optimal agricultural production requires thorough investigation of how a given crop interacts with the environment and various cultural practices such as fertility management, plant population, tillage, etc.

Proper fertility management is essential for high rice (*Oryza sativa* L.) grain yields. The rate and timing of N is a fundamental component of proper management. Turner and McIlrath (1981) conducted N rate and timing studies on amended and till cultures in Texas. Results of these studies on main crop indicated that as N rate increased up to 204 kg ha⁻¹, applied over the growing season, all yielders increased in grain yields. Furthermore, the effects of main crop N rates and timing on ratoon yields of both cultivars were not related to main crop N rate or phase. Applying main crop N at or near heading (H) increased ratoon yields but depressed

main crop yields due to lack of N at main crop panicle differentiation (PQ). Turner and McIlrath concluded that main crop N applied at PQ and N would have increased rice and fallow yields over time. Nitrogen rates up to 112 kg ha⁻¹ applied after main crop harvest, increased rice yields. Adequate rice yields of 2.7 to 3.8 t ha⁻² were obtained in this study when N was applied at or near main crop heading and 112 kg N ha⁻¹ was applied to the rice crop.

In Louisiana, Brackin et al. (1980) noted that splitting N applications generally reduced main crop grain yields of wetland cultivars compared to 300 kg N ha⁻¹ banded in a Crowley with fall soil 2 d prior to permanent flood. However, contrary to the Texas studies, the Louisiana research clearly showed that wetland and fall cultivars both had higher rice yield when main crop N management was optimal.

Rice performance trials conducted by Jones (1989) on phaeoplastic clays in central Florida have demonstrated main crop grain yields of 'Galfrida' and 'Lakeland' at 4400 and 3200 kg ha⁻¹, respectively. These yields were achieved at a growth rate of 120 kg ha⁻¹, applied before permanent flood. Jones and Smith (1990) conducted field studies of N on phaeoplastic clays and found 200 kg N ha⁻¹, applied after main crop harvest, produced grain yields over 3500 kg ha⁻¹ for both Galfrida and Lakeland.

The objectives of this study were to investigate the effects of N rates, applied to main crop, on main and rice crop yield, yield components, and rice tillering grown on reformed phaeoplastic swelling sand clay-low rice genotypes, differing in growth habit, and five main crop N rates were studied.

LITERATURE REVIEW

Exciting Fossil Phosphate Clay Soils

Biological Services

The geological process of phosphate deposition began 35-40 million years ago during the Eocene era (Benedict, 1981). During this era large crabs and fishbones formed in the Eocene sea bed. As Eocene waters gradually evaporated, large and small estuaries formed in the rock cavities and fissures. These estuaries braced with fish, reptiles, and various plants whereby processes of continuous concentration and decomposition over millions of years formed the phosphate matrix found today (Byatt, 1981).

These rich phosphate deposits in Florida remained undiscovered until 1881 when Captain J. Francis De Rosa discovered a bank of fossil remains while exploring the Peace River in central Florida. Upon subsequent analysis of these samples and prospecting by Col. T. J. Woodhead, a retired government engineer, the Arcadia Phosphate Co. was formed. During the next 45 years following this discovery, nearly 280 mining companies were formed to tap Florida's phosphate-rich Bone Valley formation in central Florida. This formation, so named for the large number of fossilized bones deposited there, is a roughly rectangular area 40 miles wide and 50 miles long. It includes parts of Polk, Hillsborough, and Marion counties (Barnes of Bone, 1934).

Phosphatic Clay Characterization

Phosphatic clay soils are by-products of phosphate processing. The raw material prior to processing is called phosphate matrix and consists of approximately equal thirds of phosphatic rock, sand, and clay. The phosphatic rock is removed at the beneficiation plant while sand and clay fractions are removed to separate disposal areas. The clay fraction, suspended in a water slurry, is pumped back to old strip-mined cuts. These mined cuts are constructed to form earthen dammed settling ponds ranging from 4-12 ft above ground level (Barnes et al., 1981; Lamm et al., 1982). At present, approximately 100,000 ha have been sited in the state of Florida by the phosphate industry. Over 65% of this area results in phosphatic clay settling ponds (Barnes, 1984).

Phosphatic clays can be defined as a mixture of silt and clay particles approximately 100 μ in diameter and less. The clay minerals found in silted soils in relative order of abundance are smectites, calcic-muscovite, illite/smectite, mica, kaolinitized clay minerals, halloysite, quartz, vermiculite, crinoidite, dolomite/siderite, feldspar, attilite, iron phosphates, and a number of heavy minerals in trace amounts (Barnes, 1984).

Attapulgite, a hydrated magnesium silicate, has important implications for settling properties of phosphatic clays. This silicate largely controls several important physical characteristics of the phosphatic clays (PC) such as reducing phosphatic settling rates, terminal velocity, and viscosity (Lamm et al., 1984).

The physical properties of PC can be characterized by size, morphology, and shape. Clay particles are 100 μ in diameter or smaller and

typically still are less than $1\ \mu$ in diameter. Particle shapes also greatly influence the physical properties of the clay. Attapulgite consists of rods or fibers. Illite and kaolinite are flattened platelike, and smectites are thin sheets (Banerjee, 1983).

Chemical characteristics of phosphatic clays have revealed pH to be neutral to slightly basic, cationic E equal to approximately $3\ \text{g kg}^{-1}$ and P equal to approximately $8\text{--}9\ \text{g kg}^{-1}$. The pH, though slightly basic, is still in a range where P, Ca, Mg, K, S, Na, and E are available to the plant. Fe, Mn, Cu, and Zn availability may be a problem at this pH (Jarvis, 1974). In fact, Mn deficiency problems have been reported in vegetable crops (Gardner and Barker, 1988). These cation ratios are naturally high in P. Cation exchange capacity (CEC) for phosphatic clays is reported to range from 8 to each kg^{-1} (dry wt.) of clay. Most of this exchange capacity is tied up by Ca and Mg (Banerjee, 1983).

Some of these clay mineral constituents have agricultural applications. Smectites, for example, have a large cation-exch capacity enabling them to hold large amounts of water. The CEC of montmorillonitic smectite is pure form is 110 each kg^{-1} and mostly dominated by Ca and Mg with minor substitution of Na and K (Jarvis et al., 1975). The carbonate-fluorapatite fraction of phosphatic clay that is not removed during ore processing accounts for the principle loss of phosphate in the smelting process. This unaltered mineral accounts for an adequate phosphate content of the clay which is available for crop usage. Trace elements important in plant nutrition are also present in the ore, including Na, K, and Zn (Banerjee, 1983).

Rhizobial crops offer both advantages and disadvantages for agricultural production. Slow decomposition rates, poor trafficability of heavy farm machinery after rain, establishment of some crop species, and concerns about uptake of detectable levels of herbicides, especially by leafy green plants are challenges that require further research. Advantages of these crops include generally adequate fertility and neutral pH, good water-holding capacity thereby reducing irrigation demand, demonstrated ability to produce small grains, legumes, energy crops, and possibly others. Overall, RC provide considerable opportunity for agricultural production.

Source of Rhizome Crop Production

Introduction

The word rhizome is likely to have originated from the Latin word rhizoma which means to cut down or cut (Qualls and Harb, 2004). Wikstrom (1982) defines a rhizome as a basal member for propagation, such as in bamboo, sugarcane, and pineapple. In grasses, rhizome tillers typically develop from basal or axillary buds that exist in the stables and the root system of the main crop (Hudson et al., 1979). The growth and vigor of rhizome tillers mostly depend on the carbohydrate reserves in the stables and root system of the main crop (Zandbergen and Lamm, 1979). Management of the rhizome crop, therefore, begins with proper main crop management.

Rice has the ability to rhizome, although considerable variability exists in its rhizome growth duration and yields. Graham et al., (1989) state that main crop maintenance can range from 65 to 175 d depending on cultivar, while rhizome crop maintenance can range from 40 to 115 d. Therefore, combined maintenance periods indicate that main crop rice

followed by a relayed crop can take about one month less to mature than late season/late-planted rice crops. Choudhury further states that relayed grain yields range from 4 to 140% of main crop yields. High potential yield of the relayed crop and the reduced growth duration of relayed rice indicate relayed cropping may be a practical way to increase annual grain production per unit area and per unit time.

Advantages of relay cropping include lower production costs due to savings in land preparation, transplanting or direct seeding, and crop maintenance during early growth (Fluckhardt et al., 1979; Choudhury et al., 1985). These advantages translate up to 85% savings in labor requirement and 25 to 35% savings in cost of production (Tonditore and Samsom, 1978). The benefits of a reduced growth period in this system are clearly evident in areas with a limited growing season due to inadequate rainfall or irrigation and potential cold weather damage. In addition, valuable resources such as power, labor, and cash are freed up for other uses (Pillay and Baruah, 1984). Relay cropping can be used in crop breeding to maintain the genetic purity of a cultivar through several seasons. Often the relayed crop uses less irrigation water and fertilizer than the main crop due to a shorter growth duration (Choudhury et al., 1985).

The disadvantages of relayed rice production include a wide variety of problems. Yield data collected by the International Rice Research Institute (IRRI) on 107 cultivars grown in India, Brazil, Philippines, USA, and some countries in Africa, show that 100 yielded less than 300% of the main crop while 70 yielded less than 50% (Choudhury et al., 1985). Extensive breeding work remains to be done to improve selected relayed plants and other traits.

Ratoon grain quality is often inferior to that of the main crop grain. A comparative study by Smith et al. (1978) on kernel quality of main and ratoon crops reported that ratoon kernels were on average smaller and lighter in weight than main crop kernels. Seed and total dried rice yields of the ratoon were generally lower than main crop samples. Also, some physicochemical properties of ratoon crop samples were consistently lower than that of the main crop. The protein content of the ratoon kernels varied widely ranging from 1 to 26 higher than main crop kernels. Other problems of ratoon rice are uneven maturity which can make harvest difficult and expensive (Tison and Bernade, 1988). Injurious insect, weed, and disease problems may build up in the ratoon from residual pest problems in the main crop (Hassim et al., 1973). There is also lack of assured returns from input investments due to generally low ratoon yields. Finally, ratoon cultural practices need to be better developed, especially for cropping systems in developing countries (Chatter et al., 1984).

Rice ratooning is a viable agronomic practice in a number of countries worldwide and especially in the Southern Asia. Internationally, rice is ratooned in India, Japan, Columbia, Philippines, Brazil, Thailand, Taiwan, and the USA (Krisdanasuthy, 1988; Chatter et al., 1984; Swift and Beardsall, 1982). In South and Southeast Asia only 14% of rice land can support two crops of rice a year. The remaining rice production areas are rainfed, or have inadequate water resources (Krisdanasuthy, 1988). In rainfed regions there is generally only one rice crop grown per year. The residual moisture left in the soil at the end of the rainy season is often adequate for a second, short season crop

such as a rice raton (Faber and Delotto, 1977). This is especially true if the wet season lasts for six months.

In the USA, commercial rice ratooning was established in 1962 with the release of the 90-100-d cultivar 'Rella Raton' for the golf coast of Texas. Until the release of Rella Raton, no US cultivar was sufficiently early-maturing to produce reliable robust crops (Jeffrich et al., 1988). Today approximately 50% of the rice acreage in Texas and south Louisiana and about 70% of the rice hectares in Florida are ratooned annually (Jeffrich and Turner, 1988). The growing season in other rice production regions of the SE, such as Mississippi, Arkansas, and Mississippi, are too short for commercial rice ratooning (Jeffrich and Turner, 1988).

Cultural Practices of Ratoon Rice Production

Specific cultural practices involved in rice ratooning cover a wide range of agronomic aspects. The more noted practices are cutting height of the main crop culms, water management, fertility management, and variety selection. In addition, land preparation of the main crop, main crop establishment, spacing (in transplanting systems), time of harvest, and crop duration are also important aspects. Much of the scientific literature on rice ratoon cultural practice is based on transplanted rice while less information is available on direct-seeded rice, which is grown throughout the USA.

Main crop stable cutting height has been studied extensively for its effects on ratoon traits, yield, and yield components (Chen et al., 1986; Lundberg and Suresh, 1988; Faber and Delotto, 1977). Most of the research involves effects of cutting height on transplanted rice. Some field trials on direct-seeded rice have been conducted in Texas (Jedrej

and Graft, 1989). Perhaps the most obvious aspect of stubble height is the number of heads remaining on the culm for tiller regrowth. Some cultivars produce robust tillers from early culm heads at the higher nodes of the main crop stubble. Other cultivars generate robust tillers from basal nodes (Quastner and Samson, 1979). Therefore, cutting height for those cultivars with primarily basal robust tillers may be less important.

The results of cutting height studies on robust yields vary. Brinkmann et al. (1986) reported that cutting height had no effect on robust grain yields but exerted a significant influence on straw yield. Prosser (1976a) reported highest robust yields from main crop cutting heights of 8 and 4 cm compared to 8 and 18 cm. The opposite results were reported by Jones and Prosser (1982), whose studies noted lower robust grain yields at lower cutting heights than higher cutting heights.

More recently, Baker and Bellotti (1992) conducted a series of experiments on main crop cutting height and its effect on robusting. They found that a 15 to 26 cm cutting height is optimum for robust grain yields. At shorter cutting heights, a significant increase in dead plants occurred. They also noted that growth duration increased from 32 to 38 d as cutting height decreased. Staller delays in maturity due to lower cutting heights were reported in Texas and elsewhere (Prosser, 1976a; Rogers and Graft, 1989; Graft, 1989; Graft and Hancock, 1990).

Samson (1980) reported that different cutting heights caused significantly different grain weights, panicles per hill, panicles per square meter, robust grain yield, flowering hills in transplanted rice, and growth duration. Baker and Bellotti (1992) analyzed yield components at

different cutting heights and water management regimes and found that plants cut at ground level and not reflooded for 4 d or more after harvest produced more particles and were filled grains per particle than plants cut at 15 cm. Plants were lower at 0 cm cutting height due to a higher number of standing tillers.

Ratoon crops usually grow more tillers per hill than the main crop. Prasher (1976) noted the number of tillers varied with cutting height over growth stages. Fifteen days after cutting main crop stubble, tiller counts were made and tillering was shown to increase as cutting height increased from ground level to 15 cm. Above 15 cm, the culm was killed and died.

Water management for ratoon crop production has been shown to have a pronounced effect on tillering. Budge and Smith (1983) recommended flooding or light flooding immediately after 8 applications to stubble afterwards the soil must be kept moist but not flooded for two weeks after main crop harvest until ratoon tillers are 10-15 cm tall. From this stage until ratoon crop harvest, a 3-5 cm flood should be maintained.

Shigel and Wilson (1981) reported opposite results from a water management study. Application of a 5-8 cm flood immediately after main crop harvest resulted in 50% higher ratoon grain yield and more uniform and rapid tillering, than a series of short term floodings for adequate moisture followed by a continuous flood. The main crop cutting height was 40-45 cm.

Tabor and DeBolla (1977) studied the effects of main crop cutting height and ratoon water management. They found that if the ratoon field was flooded immediately after main crop harvest, ratoon yields were 8 and

2.8 t ha⁻¹ at 0 and 15 cm cutting heights, respectively. A high percentage of missing tillers was reported when the main crop was cut and a continuous flood was applied immediately following main crop harvest. The number of missing tillers decreased as the time between harvest and flooding increased. No differences in yield existed between ground-level cutting height and 15 cm when flooding was delayed to 30 d after harvest. However, with such a long delay in flooding, weeds became a problem. Baker and Isabella (1977) therefore recommended a 15 cm cutting height.

Some dry-season rice cultivars have been noted to produce more robust tillers and higher yields when water was abundant than when water was in only moderate supply. Proctor (1974) found that a significant interaction existed between main crop cutting height and first season seedling or tillering percentage. With lower cutting heights of 0, 4, and 9 cm, delaying return flooding for 4 to 6 d was superior to flooding one day after main crop cutting.

Fertilizer inputs and management are of critical importance to main crop yields and also largely influence return performance. Nitrogen fertilizers have a significant effect on return growth and yield but will be discussed in detail later in this review. Hodges and Davis (1980) showed that additional P and K did not give an economic increase in return yield provided both these nutrients were in adequate supply on the main crop. Sufficient amounts of these plant nutrients applied to the main crop were still available to the return crop (Davis, 1980). In another study by Magal and Leonard (1974), rates of 0, 5, and 8 were applied to a return crop in a factorial combination and no response to added P or K

in yield, plant height, or straw grain milling yield were observed. There were no significant R/P or S/P interactions.

Cultivar differences in retarding ability have been widely reported by many investigators (Krishnamurthy, 1980; Chakrabarti et al., 1985; Chatterjee et al., 1985; Subudewanto, 1985; Satgas and Frick, 1986; Corti and Bechini, 1986). Krishnamurthy (1980) has drawn some general conclusions from these reports. There exists a high degree of genetic variability among cultivars in their retene yields. Average retene yields were 40% that of the main crop and showed a 50 to 40% reduction in growth duration. Retene yields ranged from 0.1 to 9.2 t ha⁻¹. Chakrabarti et al. (1985) and Bittell-Labaree (1986) have compiled tables listing rice cultivars with promising retene yield potentials.

Cultivars in the USA also show considerable variability in retene yield potential; in Texas, Bittell et al. (1988) reported coefficients of variation for retene yields to be double or triple those of the main crop. A 1985 cultivar trial in southern Texas identified four cultivars with acceptable retene yields (1.2 t ha⁻¹ or higher) including two commercial cultivars with significantly higher total yields of 18 t ha⁻¹ or more. These two commercial are Lonestar and Safford. Generally, retarding is only obtained from early maturing cultivars on the Gulf Coast of Texas and southern Louisiana.

In retene rice, six genotype components have been identified that contribute to a successful retene (Bittell-Labaree, 1986). First, cultivar differences exist as to the location of tiller origin on main crop plants. Second, high carbohydrate concentration in main crop cycles was related to retarding ability of Pusa's cultivar. In studies where

carbohydrate supply to the stem was manipulated, culm growth was viewed as an indicator of the physiological situation of the crop (Ishii and Iwari, 1983). Third, since senescence of photosynthetic surface has been suggested as a vital trait that regulated culm growth because new growth can use any remaining main crop photosynthetic surface. Fourth, main crop/straw crop total duration is strongly controlled genetically and is an essential factor to culm success in these areas with a limited growing season. Earliness is favored for adequate maturing ability. Fifth, graining ability as expressed by a sufficient number of tillers per unit area is partly a vital trait and is reported to be highly correlated with culm yields (Ishii and Ikeda, 1981). Sixth, the degree of disease resistance is especially important for straw agents which affect culm crops more severely than main crops.

A trial conducted at IRI in transplanted rice investigated the effect of tillage methods on several plant characteristics of main and straw crops. There were four tillage treatments which included zero till, harrow followed by harrowing, harrowing alone, and plow followed by harrowing. Notable effects in the main crop were a significantly lower percentage of sterile spikelets and a trend of higher grain yields with the plow and harrowing tillage treatment.

The straw crop had a significantly higher number of tillers and panicles per square meter with the harrowing and the plow and harrowing treatments. Straw yields were also significantly higher with the plow and harrow tillage treatments (Ishii and Ishihara, 1982).

Comparative studies of transplanting and direct-seeding effects on culm success are limited and few in number. In the USA, direct-seeded

rice has given acceptable rubber yields in Texas (Bellich et al., 1989; Hedges and Isatt, 1989; Isatt and Branderli, 1989). In 1988 a survey of Senegal, Guyanese, and Laotian cultivars achieved rubber yields of $2.2 \pm 1 \text{ kg ha}^{-1}$, $1.2 \pm 1 \text{ kg ha}^{-1}$, and $1.4 \pm 1 \text{ kg ha}^{-1}$ respectively, which ranged around 50-22% of main crop yields (Bellich et al., 1989). In the Philippines, trials with direct-seeded rice in a relayed crop system with adequate water resulted in a $2.2 \pm 1 \text{ kg ha}^{-1}$ rubber yield in flooded fields (Chaoan et al., 1989). There is an advantage of direct-seeding main crop rice for the rubber crop because of the resulting large number of plants per unit area. Each of these plants only needs to produce a few tillers which result in a high number of tillers per unit area relative to transplanted rice (Chaoan et al., 1989; Gendria and Jensen, 1979).

Higher main crop plant populations increase tiller number per unit area and would suggest an increase in rubber tiller number per unit area. In transplanted rice systems, higher main crop tiller counts are not translated into proportionately higher rubber tillers per unit area because the number of alar/leg hills increases with closer spacing of main crop rice (Rahar and Roberts, 1987). They found that fields on plant spacing gave the highest number of alar/leg hills when compared to 20x20 cm and 30x20 cm plant spacings. Yet they reported that rubber yield was not significantly affected by plant spacing.

Jones and Snyder (1987) conducted seedling rate and row spacing studies that support this conclusion. Experiments were conducted using drift-seeded hill and seedbed cultivars at seedling rates from 50 to 150 kg ha⁻¹ and row spacing from 15 to 25 cm. Rubber grain yields of both cultivars were not significantly affected by main crop seedling rate, row

spacing, or seedling rate or row spacing interaction. There were significant main plot differences between cultivars among tests. Increased seedling rates significantly increased rubber particles per square meter but decreased filled grains per particle in all tests for both cultivars.

The stage of maturity of male crop at harvest may affect rubber performance. The best time to harvest is when culms are still greenish (Griffith, 1965; Soren and Frank, 1982). Cutting the male crop before or at full maturity when rubber shoots have just begun to grow is recommended (Chakravorty et al., 1979; Sankhap, 1984). However, Bailey and Subbarayan (1980) found that harvesting at 20, 40, and 60 d after male crop flowering did not significantly affect rubber yields.

Not only the stage of male crop maturity affects rubber performance but male crop duration also influences rubbering ability. In some temperate areas, very early maturing rice cultivars are recommended for successful rubber cropping because they do not need to be cut as early as later maturity cultivars. The use of very early cultivars allows for a better growth environment later in the season (Evett and Bucklell, 1982). Such very early 100 d cultivars as Balle Pata, Bhambale, and Lalella produced good rubber yields in the wet forest of Java (Pinto et al., 1978). Similar results have been reported for early maturing cultivars (Griffith et al., 1980; Sledge and Evett, 1980; Evett, 1984). With very early maturing cultivars will usually produce a successful rubber with proper management, early maturing cultivars of about 120-130 d crop duration require at least a 180-200 d total growing season for a successful rubber crop (Sledge and Evett, 1980). Mid-season and late

maturing rice cultivars in the USA will typically not produce a successful rice crop, although there are some mid-season cultivar exceptions.

Sokal and Grossall (1978) studied intermediate duration cultivars of 115 d or more and found they produced higher rice yields than early maturing cultivars of 115 d or less. Seed weight was significantly correlated with volume grain and volume crop densities which may indicate that high volume yields require selection of cultivars that have volume densities of more than 70 d

Effects of pests on volume rice

Insect pest accumulation on rice crop stands is one of the major hazards affecting volume rice production. Theoretically, volume rice should sustain higher insect populations than a single or a double rice crop controlled by a fallow or rotation with a non-rice crop (J. Hainge and Brady, 1988). Researchers have observed grain leafhoppers to multiply faster on the volume crop and to acquire rice yellow dwarf virus from infected volume plants which is then to passed on to the subsequent rice crop of rice (Jhon and Koh, 1988). Also volume will generally favor insect population increases of leavers, gall midges, leafhoppers, and others during the off season. Volume crops act as hosts for maintaining these deleterious populations (Kristiansen et al., 1988)

Oslo Eric and L'Orange (1988) studied volume rice insect species, predator species, and flooding regimes with the following conclusions:

-Volume is a poor host for rice short smut (*Ustilidia shillingii*). Its build-up is not encouraged due to a shortened vegetative state.

-Leafhoppers (*Circulianella tenellus*) and planthoppers (*Silenevoria lutea*, *Scutella fuscipes*, and *Metatibia chinensis*) have the

harvesting main crop but return to cultivate the rubber crop. Yet they are less serious on rubber due to natural predators.

-Approximately 1/3 of rice larvae (*Scirpophaga incertulas* and *Chilo suppressalis*) can be carried over from main crop stubble to the rubber but due to early rubber harvest are not generally serious pests.

-Leaf folders (*Homalacoccus nodulalis*) are attracted to the reproductive phase of the rubber.

-The rubber is a favorable habitat for several predators due to lack of food preparation. Spiders (*Larisa manducivora*, *Misena formosa*, and *Intercepta* spp.) and staphy bugs (*Pentatomidae*) are major phloem-sap predators and accumulate on rice stubble after harvest.

-Continuous paddy field is a good insect pest-problem conservation cultural practice.

-Due to the insect vector of yellow dwarf and tungro viruses, releasing cultivars that are highly resistant to virus are needed.

Though rice rubber fields are favorable habitat for natural predators, the judicious use of pesticides can be warranted to control insect population buildup on the rubber crop. The application of granular insecticides, such as carbendazim, phorate, and carbo, or spray systems; insecticides such as diazinon or phosphamidon, immediately after main crop harvest may be sufficient to control insect pests in the early rubber stages. One time spraying of diazinon or phosphamidon at rubber ring bark may substantially reduce later insect incidence (Sapaguirre et al., 1988). Serfs effectively controlled *Homalacoccus* spp., an important insect vector for tungro and yellow dwarf virus in India.

Cultural practices such as clearing the stubble after rice crop cutting may serve to control the source of disease inoculum, insect pests, and disease vectors (Sagoraja et al., 1988). Fisher and Infante (1977) noted that greater cutting heights of rice crop stubble favored greater infection by grassy stunt virus than not (*Chloris viridis*), which is usually not a serious problem in the rice crop, but damage rubber crops due to weakening of the host plant at the time of cutting. Infante (Infante 1988a), an important rubber disease in India is capable of causing 100% rubber loss from infected rice crop stubble (Sagoraja et al., 1988).

Though little research has been done on the importance of diseases in rubber cropping systems, some basic investigations have yielded important information. Rice is infected by a variety of diseases caused by bacteria, fungi, virus, and mycoplasma-like-organisms (MLG), while only some affect rubber crops. Climatic factors such as high humidity and high temperatures, will influence the severity of disease damage to rice crop and rubber crop (Infante, 1981).

Major fungal problems in rice rubbers were reported by Sagoraja et al (1988). Brown leaf spot (*Exserchium aeshmanniae*) is an important fungal disease in both transplanted rice crop and rubber. Fungi survive on the stubble and stubble left after cutting and is the main source of infection for the system.

Perhaps the most serious disease threats to rubber systems are viruses and mycoplasma-like-organisms (MLG). There are six widespread and economically important diseases: fungus, grassy stunt virus, ragged stunt virus, chlorotic streak, necrotic mosaic virus, and yellow dwarf. These

diseases either go unnoticed in main crop or become symptomatic at later main crop stages. Affected rice plants resemble those showing typical symptoms and sometimes cause or delay crop failure (Sengupta et al., 1980). Though a few genotypes have been identified in India and elsewhere that are resistant to some of these diseases, cultivars that have good releasing ability and maintain disease resistance should be developed.

Das and Faldutier (1988) have worked with diseases and disease management in relation to rice and have reported several important conclusions from their studies:

- If rice cultivars possessed disease resistance, the same level of resistance was present in the relation.
- If the main crop had a systemic disease, the disease was unlikely to produce any relation tillers.
- Yellow dwarf, caused by an RNA virus, was often observed in the relation crop, probably due to its long latency in rice plants.

Sheath blight and stem rot affected main crop as well as relation crops but their effect on retarding was erratic.

- It appears to be more effective for relation production to manage sheath blight and stem rot in the main crop rather than in the relation crop.

Work conducted at IARI (1979) on reduced tillage or zero tillage, as in a relation crop system, resulted in weed species shifting from annuals to perennials. Perennial weeds are more tolerant of herbicides and they need to be controlled on the main crop to minimise their impact on the relation crop. Annual weeds are more easily controlled in relation with manual or mechanical weeding or with chemical treatments (Pendaria and Bhowmik,

1984). Proper water management in continuous flooded paddies can provide adequate weed control for main and ratoon crops.

Effects of Temperature and Light on Ratoon Rice

Low temperatures are a serious constraint for ratoon production in temperate regions, if the growth duration of the main crop and/or ratoon crop is too long. Injury to rice plants by cold temperatures also occurs in tropical regions such as Colombia, Indonesia, India, Nepal, Bangladesh, China, and other countries (Debata, 1981). The physiological result of cold damage is pollen sterility when cold night temperatures occur 12-24 d before heading (Barker and Peterson, 1979). Thus, if main crop or submergence crop duration extends late off season cool temperatures, yields can be significantly reduced.

Temperature effects on ratoon crops have received limited attention by researchers. Quader's (1981) work on temperature effects demonstrated that when main crop rice was exposed to low temperatures of 15/20 C° (day/night) at the heading stage, rice in three times more local ratoon tillers grew compared to high (25/25 C°) or normal (20/25 C°) temperatures. At the 25/20 C° temperatures, ratoon grain yield was significantly lower due to high tiller sterility. There was no difference between high and normal temperature effects on ratoon yield. Ratoon crop duration was lengthened to 36 d at 25/20 C° and was shortened to 30 d at 20/25 C° temperatures.

Schill (1988) showed the effects of light and temperature on ratoon regrowth resulting from main crop tillers cut 30 d after harvest and transferred to four different environments. The environmental treatments included 20 C° with light, 20 C° without light, 25 C° with light, and 25 C° without

light. It is found that over a 3-week period after cutting, culm weight and percentage of culm tillers showed higher values in 20 °C than in 25 °C and in sunlight than in darkness. The maximum percentage of culm tillers occurred at or before 10 d after cutting at the 20 °C temperature, and at 10 d after cutting at 25 °C. Culm height was higher in 20 °C than in 25 °C but showed no difference between light and dark. Rice crop stem base weight decreased more rapidly at 20 °C than at 25 °C during the first 25 days after cutting. The sum of stem base weight and culm tiller weight was fairly constant over the 25-d period following cutting for all treatments except 20 °C in light. The increase in weight of the treatment in 20 °C in light suggests that its foliage contributed photosynthetic products to its own weight gain. The culm tillers in the dark treatments apparently consumed tiller stem base substances for respiration.

Quinn (1980) noted that shading the rice crop during the period from flowering to 7 d after harvest significantly decreased culm grain yields more than shading rice crop from late milk to 7 d after harvest or at harvest to 7 d after harvest. There was a 12% increase in culm yields in the excluded plots. When 30 kg N ha⁻¹ was added during milk stage and 15 d before rice crop harvest, no change in culm yields were observed with different shading periods. Isari and Sood (1981) cut the tillers of rice plants two weeks after 8 and placed them in full sunlight, 50% shading, and 75% shading. They observed that culm weight, height, and percentage of culm tillers were the highest for full sunlight followed by 50% and then 75% shading. Stem base weight decreased linearly

with increasing shading suggesting a correlation with reduced nitrogen tiller weight, height, and percentage of nitrogen tillers.

Effects of Nitrogen

Basal-root Rice

Nitrogen is the rice plant is the most limiting element for growth and yields throughout rice-growing regions of the world (Halla and Turner, 1964) and is required throughout the development of a plant to maximize growth. Nitrogen is a constituent of both structural (i.e., cell walls and membranes) and nonstructural (i.e., enzymes, chlorophyll, and nucleic acids) cell components. Nitrogen is supplied either from soil mineralization processes or it is fixed from atmospheric nitrogen by symbiotic bacteria. During reproductive growth phases, such N is remobilized from vegetative tissues via hydrolysis of proteins to amino acids (Tanaka et al., 1964).

Isleris (1961) lists six effects of N on rice: a) gives dark green color to plants as a component of chlorophyll; b) promotes increased height and rapid growth and tiller number; c) increases size of leaves and grains; d) increases number of spikelets per panicle; e) increases filled spikelet percentage in panicles; and f) increases protein content in the grain. Most of these factors directly contribute to increased yields of rice production. Tanaka et al. (1964) noted that N applied either preplant or prior to tillering of dry-seeded rice increased the number of tillers, the width and length of leaves, number of flowers, panicles per tiller arm, and grain yields.

Rice cultivars can be categorized according to their high or low response to N. The high response cultivars tend to be short statured, with small, erect, thick leaves. The low response cultivars are taller

with deep, thin, broad leaves (Jennings, 1968). Tanaka (1964) has studied varietal characteristics of tropical rice related to high and low N response. Low-N response cultivars short and metabolize N more actively than high response cultivars with increased N application at the early growth stages. This accelerated absorption of N results in a large increase in dry weight, tillering, height and leaf area. Low-N response cultivars tend to be tall and are more susceptible to lodging at high N rates than high-N response cultivars. This early excessive growth leads to mutual shading and reduced photosynthesis in low-N response cultivars and adversely affects grain yield. Low net photosynthesis from self shading rice cultivars is exacerbated in tropical climates by the relatively low light intensities present during the rainy growing season.

Differences exist in yield component expressions between high and low N response cultivars, the most prominent difference being that low-N cultivars have a limited increase in panicle number, whereas high response cultivars exhibit a large increase in panicle number with increased N application (Tanaka, 1964).

Tanaka (1964) further reported that carbohydrate content in the straw decreased as N uptake increased while a limited N uptake caused an accumulation of carbohydrates. In the ripening phase, low-N response cultivars typically contain less starch than high response cultivars when N supply and uptake are increased. Grain formation in low response cultivars depends more upon starch stored in the straw before flowering. In high response cultivars, grain formation depends upon assimilate products produced after flowering. Therefore, N must be carefully managed to maximize yields in both high and low response types.

Nitrogen transformations in submerged soils, though beyond the scope of this review, have important implications for nitrogen & fertilizer in rice production. Due to flooded conditions N_2 diffusion into the soil is mostly inhibited resulting anaerobic denitrification of N and loss of inorganic N. Aerobic N transformations or nitrification are not completely inhibited due to the formation of a thin (1-2 cm) oxidized soil surface layer. It is in this oxidized layer that surface applied ammonia fertilizers are nitrified to nitrate and eventually are taken up by the plant, leached through the soil, or denitrified to deeper reduced soil profiles. These nitrates are thought to release N_2 transported by microorganisms through and thereby create an oxidized rhizosphere. Nitrification can then occur in this oxidized zone around rice roots. Deep placement of ammonia-N fertilizer to the reduced soil layers has several flaws. It is either fixed to an exchangeable or non-exchangeable form on clay surfaces or it is soil soluble. Mass flow of ammonia to solution to rice roots occurs. Also nitrification and denitrification between ammonia in solution and microorganisms occurs. Ammonia formed from ammonia fertilizers occurs in the rhizosphere when these fertilizers are surface broadcast. When the pH of the rhizosphere tends toward the basic range, N is lost via ammonia volatilization. Though this is a simplified version of N transformations, it is clear that N losses in flooded rice systems can be substantial. It has been estimated that generally 30 to 40% of ammonia fertilizers have been lost due to denitrification (Patrick et al., 1988; de and Barker, 1988).

Due to the low native N content of R_2 , the process of soil N mineralization may have important bearing on crop production. The

mineralization process includes hydrolysis of proteins to polypeptides and amino acids and their absorption resulting in the formation of assimilate. Broadbent (1978) demonstrated with labeled N fertilizer experiments that fertilized rice obtained 88-90% of its N requirement from mineralized soil N. Unfertilized rice received essentially all of its N through mineralization.

Several factors affect soil N mineralization such as temperature, moisture, clay content, effect of fertilizer, and effect of crop residue. Harg (1978) reported that in a tropical clay loam soil incubated under saturated conditions, the rate of nitrification increased between 28 and 35 C° attaining a maximum at 35 C°. Most of the N mineralization occurred during early incubation. The rate during the first 7 d was considerably higher than between the 7 to 28 d recovery cycle. This early nitrification pattern has been verified in field studies as well.

Flooded soils have been shown to provide more rapid mineralization of soil N than nonflooded soils, due in part to the lower N requirement of the anaerobic microorganisms and their lower rate of synthesis (Patrick and Kyte, 1964). Wetting and drying cycles stimulate N mineralization. Thus, control of soil moisture through management offers possibilities to manipulate soil N mineralization beneficial to rice production, but negatively affects efficient use of available N on paddy rice.

The presence of cellulosic material in soils with both organic and inorganic components has been known to influence the rate of mineralization of N contained in the organic fraction. Casswell et al (1984) found that N mineralization rates in a waterlogged soil increased

with decreased aggregate diameter. They concluded that smaller aggregates contained a larger portion of readily mineralized organic N.

When labeled N fertilizer was applied to soil, it was shown that a priming effect occurred in the rice paddy (Jenkinson and Rillington, 1980). An acceleration of ammonia-N production occurred from soil sources due to application of fertilizer. This ammonia production increased with the applied N until it was in the ammonia form. Mineralization rates in fertilized and unfertilized soils became similar after applied ammonia-N had disappeared from the fertilized soil.

Incorporation of crop residues into paddy soils represents an addition of organic N, but the effect on overall N mineralization may be a temporary decrease in rate, or period of immobilization, depending on the nature of straw, temperature, soil, and other factors. In the case of net immobilization, the quantity of N sequestered by microorganisms is usually lower in flooded rice than dry land rice (Gillman et al., 1988).

Fertilizer N is normally required to maximize rice yields, especially when proper cultivar, climate, and cultural practices are selected to help optimize economic benefits. Ammonia-N sources, in most cases, have proven to be more effective than nitrate-N in Indian rice systems due to denitrification of nitrate fertilizers (Jain and Turner, 1984; Evans, 1983-1986) or no differences in grain yield is observed when different sources of ammonia-N are used (Patrick et al., 1982). Differences in efficiency are related to both application method and soil conditions. However, urea is usually slightly inferior in performance to ammonia sulfate, not likely due to nitrification of ammonia following a pH increase after urea hydrolysis (Poth and Gresselt, 1989).

Urea accounts for about 20% of the N fertilizer used in the USA and approximately 30% of the N fertilizer used in Asia (Black, 1986). Urea's popularity is due to its high analysis (46-0-0) and therefore lower transportation costs. There are some innovative urea formulations such as supergranular urea and sulfur-coated urea (SCU) reported to have increased efficiency. Grasswell and Lobell (1990) studied data from 117 fertility trials in 18 countries and reported that deep placement (10 cm) of urea supergranules and the use of SCU is effective in increasing rice yields compared to traditional split application of prilled urea.

Proper timing of N fertilizers and placement are essential to efficient use of N resources. Under optimum conditions, only 60-80% of N fertilizers are recovered by the rice plant (Patrick et al., 1984). Mills and Turner (1984) suggest the following management practices: 1) Water-logged rice grown in permanently flooded conditions generally yields best with preplant N placed 5-10 cm deep in the reduced soil layer; 2) Dry-seeded rice, with intermittent flooding, typically yields best with split N applications that coincide with high density growth stages. Rice has two peak density periods, during the tillering phase when the number of panicles is determined, and early reproductive phase when the number of grains per panicle and grain weight is determined.

Nitrogen timing and rate experiments have been conducted in Texas and Louisiana, on both tall and semidwarf cultivars to determine optimum practices for maximized rice and related crop grain yields. Turner and McInnis (1984) conducted experiments in Texas on two cultivars—Lafette (tall) and Lemont (a semidwarf similar to Gallemont) which treated with different N rates and timing regimes. Main crop treatments consisted of

(112 and 182 kg N ha⁻¹) for the relatively low N response Lalaha and high (187 and 226 kg N ha⁻¹) urea-N rates on Lament, a high N response cultivar. The time of application treatments included preplant/preflood (PP/PF), PP/PF/particle differentiation (PD), PP/PF/BB (B), and PP/PF/harvest + 2wks (PB) over all N treatments. In addition, the ratoon crops were treated with 0, 90, and 112 kg N ha⁻¹ immediately after main crop harvest.

Effects of main crop showed that application of N at PB for Lalaha and Lament always produced highest yields. Applying N at B or BB rather than at PB tended to reduce main crop yields by 0.1 to 1.8 t ha⁻¹, probably because the main crop became N deficient at PB. Main crop yields of Lalaha and Lament increased significantly as total N applied at the PB stage increased.

The ratoon yields of both cultivars were not related to main crop N rate or main crop yield. However, applying main crop N at B or BB rather than at PB tended to increase ratoon crop yields of Lalaha by 0.3 to 0.4 t ha⁻¹ and Lament by 0.3 to 0.7 t ha⁻¹. Along with ratoon crop yield increases when N was applied at or near heading, main crop yields decreased apparently because no N was available at PB. It is reasonable to assume that N applied at PB and at or near B would have increased ratoon and total rice yields.

When N was applied to the ratoon crop at the rate of 0 and 90 kg N ha⁻¹ yield increased from 0.3 to 0.9 t ha⁻¹. Ratoon yield increase due to 112 kg N ha⁻¹ for both cultivars was 0.1 to 1.2 t ha⁻¹ for Lalaha and Lament, respectively. Adequate ratoon yields of 0.3 t ha⁻¹ for Lalaha and 0.3 t ha⁻¹ for Lament were obtained when N was applied at or near main crop heading and 112 kg N ha⁻¹ was applied to the ratoon crop.

In Louisiana, Franken et al. (1985) looked at the effect of N rate and timing of application on the performance of selected rice cultivars. Several cultivars including Calhoun and a till cultivar (Pang) were water-seeded on a Crowley silt loam. Nitrogen treatments were banded 7 d prior to permanent flood at the rates of 0, 24, 47, 101, 155, and 189 kg N ha⁻¹. The 101 kg N ha⁻¹ rate was also split 47 PP and 54 kg N ha⁻¹ at either P1 or panicle initiation (P1). A reduced N rate of 47 kg N ha⁻¹ was broadcast in dry soil after main crop harvest and the crop was immediately flooded. Calhoun required 101 kg N ha⁻¹ for a maximum yield of 5.5 t ha⁻¹ (rough rice at 125 maturity). Splitting N application usually reduced grain yields below that of a single 47 N application especially when a PP application of 47 kg N ha⁻¹ or less was found insufficient to prevent N deficiency before P1. This was the case for Calhoun, but Pang responded well to split applications due to decreased lodging at the higher N rates.

Franken's study, contrary to the Texas study, found that main crop N rates attained certain yields of Calhoun, Pang, and Pang. Analysis of the total crop yield (main and rotation crops) showed that 101 kg N ha⁻¹ PP on the main crop gave highest rotation yields and total yields for all cultivars. The same trend was true for the other cultivars. This study clearly showed that optimum N management in the main crop favored optimum grain yields of the rotation crop. It was also observed that response of the rotation crop from a main crop stubble was influenced by main crop N rates. Starch response was generally more rapid to low N rates of main crop than to moderate to excessively high N rates. The authors speculate that this response to N is likely due to a higher concentration of carbohydrates reserved in the stubble of low main crop N treatments at N

and 24 kg N ha⁻¹ where grain yields are low. The higher rate crop yields with higher N rates probably depleted the carbohydrate reserve in the stubble of these N treatments and reduced regrowth rates.

In another experiment by Branson et al. (1985), Lebanon, a till cultivator, and several combinations including drill sowing, were drill-seeded and fertilized at 0, 24, 47, 101, and 180 kg N ha⁻¹ applied at P0. The 180 kg N ha⁻¹ rate was also split with 60 at P0 and 24 kg N ha⁻¹ at P1 and 63.2 at P2 and 33.2 kg N ha⁻¹ at P3. Maximum grain crop yields were obtained at the 180 kg N ha⁻¹ rate applied P0. This N rate was higher than expected on a high organic matter Marshland clay soil. The authors speculated that a failure to maintain a continuous flood resulted in reduced N fertilizer efficiency due to denitrification and volatilization. Split applications resulted in significantly lower grain yields of all cultivars than a single P0 application of 180 kg N ha⁻¹. Split N applications are usually less effective than a single P0 application of total N in a drill-seeded system if the P0 N rate is high enough to provide normal plant growth and development through P3.

Many applications of N on cultivars susceptible to a particular insect or group of insects may approximate serious pest attack. A series of experiments conducted in the Philippines have demonstrated that cultivars gave a higher yield response to N with a higher level of insect control than with low control levels. Furthermore, these investigations show that N efficacy depends not only on water relations but also partial resistance to insects and diseases (Jalilov and Rasulov, 1984).

Leaf area index (LAI) is highly correlated to grain yield (Jalilov and Rasulov, 1985). In a date of planting study by

Belatta and Jordan (1970), grain yield of four cultivars increased linearly as N levels increased to 120 kg N ha^{-1} and as solar radiation increased to a high of 28 kcal cm^{-2} .

The efficiency of seed control influences the response of rice to N fertilizer. Experimental evidence suggests that without adequate weed control, fertilizer should not be applied (Belatta, 1980).

Water management likely affects the efficient use of N fertilizer by tropical rice. The water regime of a field partly determines the oxidation-reduction potential of the soil which in turn affects nitrification and denitrification (Belatta, 1980).

Ratoon Crop Rice

Nitrogen fertilization is necessary for optimizing both the main crop and ratoon crop performance. In field trials conducted at IRRI, increases in N rates applied to the main crop resulted in increased main and ratoon crop yields. The ratoon crop also had an increased number of filled grains per panicle (JMA, 1970). Baker and Belatta (1971) reported ratoon yield increased to 1.5 t ha^{-1} with application of 80 kg N ha^{-1} to the ratoon crop. However, 80 kg N ha^{-1} was applied to the main crop at PI and residual N may have remained for the ratoon crop. Thus optimum N level for high ratoon yields is likely higher than 80 kg N ha^{-1} . East (1964) suggested that a rate equal to 75% of main crop fertilizer be applied to the ratoon crop and application should be immediately following main crop harvest for maximum efficiency. Nitrogen fertilizers should be placed close to the stubble row to ensure rapid uptake (Thurman et al., 1976).

Relate traits other than yield are also affected by nitrogen application. Ishii and Sawada (1982) found in greenhouse experiments that relate tiller weight and number decreased significantly when N was deleted from fertilizer nutrient solution. Since these traits contribute to relate grain yield, N is essential to good relate performance. The reduction of relate growth was attributed to the inhibitory effect of nitrogen deficiency adversely affecting the utilization of reserve substances in the stem base.

Proper placement of sole crop nitrogen fertilizer has been found to have beneficial effects on relate yields. Golden (1981) and Sauer (1980) stated that N placement deep in the soil during the sole crop growth increased relate grain yields by 18% over split application. The increase was mostly due to higher panicle densities. Split application in the sole crop delayed flowering, harvesting, and lowered leaf area index in the relate crop.

Golden (1981) noted that deep soil placement (first cut) of N on the relate crop produced significantly higher yields than equal rates of broadcast N. This yield increase was due to higher numbers of panicles per plant, more filled spikelets per panicle, and more vigorous plants.

Carbohydrate reserves remaining in the sole crop culms after harvest are critical for successful performance of a relate crop (Ishii and Sauer, 1982; Ishii and Sawada, 1982). Ishii conducted two experiments that help to point out the importance of stem reserve carbohydrates. The first experiment was a field study on effects of cutting time at 10, 20, 30, and 40-d after heading of sole crop and its effects on relate weight per stem, relate height, and percentage of relate tillers (Ishii, 1984).

Over all tiller categories tested in the study, the three major reserve variables decreased significantly after the first cut on the 10th & after main crop heading. On the 30th and 40th d after heading, (cutting time) all reserve traits slowly increased to higher levels though still far lower than measured at the 10th d cutting time. Seng and Borsari (1987) reported that rice culm carbohydrates content decreased during the grain filling period between the 30th and 40th d after heading and slightly increased afterwards. Thus, with reduced culm reserves, as grain fill proceeded, important reserve plant traits also decreased suggesting that the early reserve crop growth is dependent on accumulated carbohydrates in the rice base of the earlier plant.

Edlin and Sam's (1980) second study was a greenhouse experiment where six cultivars were subjected to three shading regimes. They included 0, 25, and 50% shade from four d before heading to 30 d after heading to regulate rice carbohydrate reserves. Afterwards, the plants were cut at 8 cm height and placed in the dark at 25 C°. No N fertilizer was added to the rice crop. Rice tiller height and percentage of culm tillers (relative to main crop tillers) were measured on a regular schedule until the 40th d after cutting. Rice weight per stem was recorded once on the 40th d after cutting. Stem bases of the main crop were measured for total available carbohydrate (TAC) on the day of cutting. The analysis shows that from 0 shade to 50% shade the percentage of culm tillers, and culm height and weight decreased correspondingly. There was a linear relationship between stem base weight per stem of the main crop and TAC per stem. Also, correlation coefficients were positive and highly

significant between weight of straw leaves and TC is the ratio crop residue and percentage of various C/Tiery, and ratios height and weight.

Ratoon Rice Growth and Development

The growth phenomenon in plants is defined by three cellular events: The first two, cell division and cell enlargement, involve increases in cell volume. The third event is cellular differentiation in which plant cells specialize into distinct tissues of different morphology and function (Sollisbury and Ross, 1962). Gardner et al. (1982) state that agronomists usually define growth as an increase in dry matter which includes cellular differentiation. Dry matter production typically has the greatest economic importance.

These processes, of course, apply to rice ratoon as does dry matter accumulation and plant density issue. The following description of main crop rice embryony also applies to ratoon rice. There are three main phases: 1) The vegetative phase occurring from seed germination to panicle initiation, 2) Reproductive phase occurring from panicle initiation to flowering, and 3) The ripening phase occurring from flowering to seed maturity (DeCatta, 1953; Masaoi, 1976; Matsuda, 1971).

Ratoon crop duration has been reported to be between 40-70% that of the main crop duration (Proctor 1976). Much of this reduced duration time is due to a reduced vegetative phase duration. Masaoi (1976) observed that the main crop vegetative phase of early maturing cultivars is approximately 50-55 d depending on temperature, pest incidence, and cultural practices. The vegetative phase of the ratoon in the Southern US is around 35 d. This condensation of the ratoon vegetative phase may be due in time saved in germination and seedling emergence.

Robust vegetative growth is unique from semi crop vegetative growth in several ways... Robust plant height is shorter and the number of panicle bearing tillers is four times to eight crop, though some robust crops have produced more total tillers than the semi-crop (Jahar and Bollett, 1977) (Katsouroulas et al., 1981). Many of the robust tillers are unproductive as some auxiliary buds were carbohydrate sink that could go into grain filling (Swati, 1982). Robust tillers develop from viable auxiliary buds left on the main crop stubble. Pengar (1976) noted that robust tillers from higher nodes formed more quickly, developed faster, and matured earlier than tillers from lower nodes in transplanted rice. Pengar (1976) and Dhill (1984) both noted that tillers generated from basal buds were all reproductive or effective tillers containing panicles and that tillers from upper nodes had short and sparse heads. The researchers in China working with transplanted, late maturing rice hybrids reported that robust tillers generated from the slightly viable buds on the 2nd, 3rd, and 4th nodes, produced panicles with more grains but a lower percentage filled spikelets from the lower nodes (Dianbei et al., 1988). Panicles from the 2nd node produced four grains but with a higher percentage fill. The 2nd node tillers were calculated to contribute 28-45% of total yield while 3rd and 4th node tillers combined produced 26% of total yield. Therefore two to three nodes should be left on the main crop stubble to promote higher robust grain yields. Another unique feature of robust vegetative growth is that robust tillers are likely dependent on the main crop root system for nutrients for at least 30 d after harvest (Jahar et al., 1981). These researchers also reported that robust tiller roots free cultivar 100 contributed 15-25% to the total root mass.

Thus, the presence of a vigorous main crop root system allows for a rapid initiation of return tillers. For example, the appearance of the first tiller of 1844 occurred between the first and tenth day after cutting, while it took from 20-24 d for the main crop first tiller to form.

The return reproductive phase is similar to that of the main crop. Bolatta (1984) mentioned four stages of the return reproductive period: 1) RI and development, 2) booting, 3) heading, and 4) flowering, pollination, and fertilization. Panicle initiation is the beginning of the reproductive phase. The panicle primordia first appears as a single stem, usually first in the main culm followed by other tillers in an uneven pattern. Panicle differentiation, when 30% of the main culm has panicles 2 cm or longer, is a more useful concept to identify the reproductive phase under field conditions. Panicle differentiation occurs 3-5 d after RI. The panicle lengthens, spikelets become distinguishable, and the panicle grows upward into the flag leaf sheath. Then booting, or swelling of the flag leaf sheath occurs and lower leaves may senesce. Heading occurs when the panicle emerges out of the flag leaf sheath. Flowering then proceeds as spikelets open, the filaments elongate, and pollen is shed from the anthers. This is a highly self-pollinated crop. In fact, it is not unusual for anthers to shed their pollen before the spikelet opens (Stansel, 1984). The flowering process takes 3-5 d starting at the top of the panicle and proceeding down to the base. Flowers are open for a few hours from mid morning to early afternoon. Anther Proliferation is completed in about 30 min after pollination. High winds and low temperatures hinder pollination while sunlight during flowering promotes good pollination (Stansel, 1984).

The ripening phase of cotton production begins after pollination and fertilization and takes 30-35 d under Florida climatic conditions. Delucia (1983) mentions three stages of the ripening process: 1) milk grain stage, when the carpocarp is being filled with carbohydrates in the form of a milky white fluid, 2) dough stage, when this milky substance dries and forms first a soft then a hard dough, 3) physiological grain maturity stage when grains turn color from green to yellow, become fully developed and become hard textured. When 90-100% of the filled carpocarp turn yellow this stage is considered to be complete.

Aspects of Growth Analysis

Growth analysis is an effective tool to study development of growth stages, environmental impact, and treatment effects on plant development. Growth analysis typically involves two types of measurements: leaf area and dry weight of plant parts at selected time intervals. From these two types of measurements a number of descriptive growth analysis terms can be calculated. Besides phenal changes, plant growth primarily involves dry weight accumulation. This growth is a function of genotype and environmental interactions and can be characterized by a sigmoid curve (Gardner et al., 1988).

This sigmoid curve is made up of 2 primary phases, according to Bellamy and Ross (1981). This curve graphically demonstrates the growth pattern of many organisms or organs, tissues, and even cell constituents. In the first phase, or logarithmic phase, the size of the plant increases exponentially with time. The rate of growth is initially slow but continuously increases and is proportional to the size of the plant. Next, the linear phase, results in a size increase at a constant, usually

maximum rate for some time. Finally, the senescence phase is characterized by a decreasing growth rate as plant maturity approaches, followed by eventual senescence. This process of growth applies to both wet crop and rubber crop rice, though the growth phases are shorter in rubber rice due to a reduced crop duration.

The slope of the linear portion of the growth curve is commonly known as the crop growth rate (CGR) (Sarker et al., 1995). Sadler (1962) defines CGR as an instantaneous measurement in time of plant net leaf increase per unit land area. The CGR of stems, leaves, and panicles can be calculated from the linear portion of their respective sigmoid growth curves which is generated from their dry weight measurements taken over the ontogeny of the crop. Sarker et al. (1995) suggested a mean CGR of $28 \text{ g m}^{-2} \text{ d}^{-1}$ is respectable for wet CI plants and $38 \text{ g m}^{-2} \text{ d}^{-1}$ is possible for CR plants. Close to a CI plant.

Dry matter accumulation is an integral of CGR over the entire growth period and is related to grain yield by the harvest index (Chikanda, 1971). Harvest index is the ratio of grain yield to total biomass yield (Donald and Reith, 1974). Actual biomass yields are next. Likely to be smaller than wet crop, yet rubber grain yields are highly variable due to genotypic and environmental influences (Chikanda et al., 1987). Therefore it is difficult to make any definitive statements about rubber harvest index values.

Important parameters of growth analysis which influence grain yield are grain-filling rate and duration. Fujita et al. (1989) conducted experiments on rice cultivars and measured effective grain filling period (1989) from flowering to the point of maximum grain dry weight attainment.

The beginning of GRR is not precisely defined. The end of GRR is generally defined as the date when there is no significant increase in grain dry weight. Yoshida and Hara (1977) reported that higher temperatures usually resulted in shorter grain filling duration and increased grain fill rate. Light intensity had no effect on these parameters.

Different methods are used to measure grain fill rate. Fujita et al. (1984) calculated grain fill rate by dividing maximum grain weight by the grain fill duration. Jones et al. (1978) used the slope of the regression analysis of seed weight against time for grain fill rate. They further state that grain filling rate seems to be more important than grain fill duration because grain filling rate was significantly and positively correlated with particle weight, particles per square meter, and grain weight.

Leaf area index (LAI) is the ratio of whole plant leaf surface area to ground area. Though LAI is only defined by leaf surface there are other photosynthetically active surfaces. According to Gardner et al. (1986) certain plant parts, such as stems, leaf sheaths, and even of some cereals, also contribute to carbon assimilation. Dry matter accumulation rate is dependent on a crop LAI (Yoshida, 1977).

Two theories are prevalent concerning the relationship between GRR and LAI. Gardner et al. (1986) noted that critical LAI and optimum LAI represent conceptual differences in the relation of GRR to LAI. In both examples GRR increases up to the LAI value at which most of the solar radiation is intercepted. After this maximum GRR is attained, the two LAI concepts differ. Critical LAI is the LAI where 95% of the solar radiation

has been intercepted. Increasing the LAI above 85% radiation interception results in insignificant (20% increase or more) shading of lower leaves and reduced LER. The critical LAI response occurs in plant species where new leaves occur at the top of the plant and fully expanded bottom leaves are shaded and therefore have reduced photosynthesis and respiration. The optimum LAI response may occur when young leaf tissue is shaded by older leaves higher in the canopy (as in sorghum) and the new, actively growing leaf tissue imports photosynthates from other leaf tissues for growth. This new leaf tissue increases its respiration which can not be matched by photosynthesis due to shading and at this point the LAI has exceeded the optimum LAI...

Fajardo and Delucia (1991) reported that a rice variety has no optimum LAI value for maximum grain yields in improved plant types. Yoshida (1982) reported similar results and stated that rice displays a critical LAI from four to eight for cultivars with erect and droopy leaves, respectively.

Rice grain yield is a function of four yield components which occur at distinct stages throughout the plant's life cycle. These components are: 1) the number of panicles per unit land area, 2) the number of florets (spikelets) per panicle, 3) the percentage filled florets (spikelets), and 4) grain size measured as grain weight. Delucia (1982) and Reinbrecht (1988) suggested the following equation to express the relation between yield and yield components:

Grain yield	Number of panicles per unit area $\times$
	Number of spikelets per panicle $\times$
	Percentage of ripened spikelets $\times$
	Weight of 1000 grains

The number of panicles per unit area is mostly determined through tillering stops by the 10th d after the maximum tiller number is attained. The supply of N and solar radiation affect this yield component at tillering (Matsushita, 1988; Ishizuka, 1973). Nitrate N₂O₃ increased N uptake, increase tiller number, and therefore, panicle number per unit area in transplanted rice, though, excess N applied before panicle initiation increased the number of non-bearing tillers. However, when solar radiation decreases in the reproductive stage, spikelet number m⁻² decreases when panicle number is too high. Odehara (1981) noted that with the combination of high daytime temperatures and solar radiation, and low nighttime temperatures during tillering, panicle number can increase without reducing spikelet number. Matsuda (1972) noted that panicles per unit area can be affected by plant density and amount of tillering. Plant density is controlled in direct-seeded systems by seeding rate and row spacing. In tillering cultivars are desired in such a system, and most tillers produce a panicle when fertilized at the proper N rate. In transplanted systems of conventional spacing, high tillering cultivars are desired to achieve optimum plant densities of panicle-bearing tillers when sufficient N and phosphorus are available.

The number of spikelets per panicle is a function of two critical periods between node-node differentiation (10 d before heading) and the end of meiosis division (5 d before heading). The first critical period

is the secondary rachis-branch differentiation stage in which the maximum number of grains is being determined. The second period is the maturing stage when grain and egg cells develop. It is during this second period that the final spatial number is determined. Abiotic stresses or plant stress, such as low solar radiation or N can cause spikelets and secondary rachis-branches to degenerate (Poluninski, 1984).

The number of fertile spikelets, or percentage filled spikelet, is calculated by dividing the number of fully developed spikelets by the total number of spikelets on a panicle and multiplying by 100. This component is developed from between each-node differentiation, approximately 10 d before heading, to the yellow grain ripe stage, about 20 d after heading (Poluninski, 1982). However, the percent filled grain is primarily determined by the end of the pollination period. Important factors that affect the percentage filled spikelets include: 1) excessive levels of N lowered the percent filled spikelets, while adequate N applied during panicle development generally increased percent filled spikelets; 2) amount of carbohydrates accumulated before heading stored in the culm and leaf sheaths; 3) low solar radiation in the ripening stage decreased percent filled spikelets; 4) lodging; 5) rate of carbon assimilation; 6) low temperature at reduction division stage can cause non-viable pollen while high temperatures at anthesis can cause sterile pollen; 7) plant vigor; 8) soil salinity; 9) drought at flowering is upland and irrigated inland rice; 10) wind at flowering can cause poor pollination, and others (Yoshida, 1983).

Grain weight is set during the period from secondary rachis-branch differentiation to late ripening. Yet, this yield component is primarily

determined from seedling to maturity under test conditions, the grain weight of rice is a stable varietal yield component (Sage and Smith, 1957). The weight of the kernel is set by the size of the hull at heading and the ability of the caryopsis to fill the hull after heading (Ratnadurai, 1960). Ishizuka (1971) stated that grain weight was affected by the accumulated carbohydrates in the stem before heading and the photosynthesis of lamina tissue and other plant parts after heading.

The following growth analysis study investigates the effects of five N rates on a wide range of growth parameters. It is the author's intention to elucidate the effects of N treatment applied to main crop rice cultivars on main crop yield, yield components, dry matter accumulation, and growth rates. Semi-structural carbohydrates concentration of culm after main crop harvest have been quantified to observe N effects on carbohydrate accumulation in stems and its effect on culm tillering.

MATERIALS AND METHODS

Experiment

Growth analysis studies were conducted at the Broad Leaved Demonstration Project (Agrium site) located approximately 10 km northwest of Eureka, FI, during the 1988 and 1989 growing seasons. The research area is part of a recently reclaimed 200-ha phosphatic clay settling pond. The annual precipitation was 502 and 1843 mm for the 1988 and 1989 growing seasons, respectively. Average monthly temperatures ranged from 21 °C to 28 °C during the April to November growing season (National Oceanic and Atmospheric Administration, 1988-89). Phosphatic settling pond clay (Phosphogoth clay) was burned and leached prior to the 1988 growing season. The wetland, in 1988, was prepared by several passes over the field with a reclaimer. In 1989, the paddy was reconstructed and reseeded. Green disks kept the area weed-free prior to planting and was used for final seedbed preparation in 1989. Plots were drilled seeded at a rate of 250 kg ha⁻¹ on April 6, 1988 and April 7, 1989 in a randomized complete block design with 3 and 5 blocks in 1988 and 1989, respectively. Individual plots consisted of seven 6-m-wide spaced rows 12.8 m in length. Immediately after planting, plots were uniformly fertilized with a broadcast application of 80 kg N ha⁻¹ as urea as a starter fertilizer and irrigated. Treatments consisted of two cultivars, "Lakeland" (Hollrich et al., 1975) and "Guthrie" (Hollrich et al., 1988), and five urea crop N rates consisting of 50, 100, 150, 200, and 250 kg N ha⁻¹ broadcast as urea.

Three R treatments include the 30 kg R ha^{-1} broadcast immediately after planting. In 1988, R treatments were applied by hand 30 d after planting (30P) (20 May) and the fields were permanently flooded immediately following application. In 1989, nitrogen was applied 20 GAP (10 May) and the paddy was permanently flooded 7 d later. The two cultivars were similar in growth duration (128 d subarctic). Plots were culled in late June 1988 and mid-April 1989 to control bird predation. Rice crop harvest was August 18, 1988 and August 5, 1989. Field and yield components were recorded (see next section for details). Immediately after harvest, main crop stubble was cut, by a hand-held gas-powered hedge trimmer, to a 15-cm height. Approximately one week later plots were broadcast with 150 kg R ha^{-1} (area). A permanent flood between 1m to 1.5m in was established immediately following R application.

Propanil: $\{[4\text{-}(2,4\text{-di-chlorophenyl})\text{propanamide}]\}$ MEC and Dalapon $\{[4\text{-}[(4\text{-chlorophenyl})\text{oxymethyl}](3\text{-trifluoromethylphenoxy})\text{butanoate}]\}$ MEC were applied for weed control on April 26, 1988 and May 5, 1989. The rate of Propanil and Dalapon was 1.2 kg ha^{-1} and 1.4 kg ha^{-1} , respectively. Propanil (2.2 kg ha^{-1}) was applied once more just prior to main crop permanent flood in 1988. Weeds not controlled by herbicide or flooding were pulled by hand in both the main and ratoon crops. No significant insect or disease problems were encountered.

Sampling Method

Two biomass samples were taken from both the main and ratoon crop for each year. Main crop biomass samples were taken at heading and harvest. Ratoon biomass samples were taken 1, 4, 8, and 9 weeks after main crop harvest (vegetative and reproductive phases), and weekly

during the ripening growth stages. Each plot sample consisted of 5 center rows 4.6 m in length cut at ground level. Samples were placed in plastic bags and taken to the laboratory for measurements. Initially, fresh weight of the total sample was recorded. Then a 10-plant subsample was taken from each biomass sample, the fresh weight recorded, and separated into green leaf blades, stems (including leaf sheaths), and panicles, when present. After recording the fresh weight of the individual plant parts, leaves from each subsample were measured by a leaf area meter (LiCor Model 2100) to determine total leaf area of the samples. Samples and subsamples were dried at 60 to 65°C for 48 h and dry weights were recorded. Dry weight per square meter for each plant part was calculated from subsample dry weights and divided by the area sampled of each biomass sample date. Aboveground plant part weight m^2 , leaf area (m²), plant height, and tiller number were plotted over all biomass sample dates. At maturity, the remainder of each plot was harvested for grain and yield components by taking 3 center rows 4.6 m in length. The number of panicles was recorded in the final harvest biomass sample. Fifteen panicles from each plot subsample were used to determine grains per panicle, grains per spikelet, and 1000-grain weight. This harvest procedure was followed for both main and rebait crops. Harvested grain was threshed, weighed, and moisture was determined with a commercial grain moisture meter. All yields were calculated as rough rice at 135 g kg⁻¹ of moisture.

Total Non-structural Carbohydrates

Total non-structural carbohydrates (TNC) was measured at the bottom 16 cm of culms when the biomass sample of the main crop was collected. TNC analysis was by the Total Nonstructural Carbohydrate (TNC) Procedure

(Christianson, 1983). Sapling samples were collected in the PMD, sealed down immediately on ice, and subsequently dried at 45 C° for 48 hr. Sapling samples were ground in a Wiley mill with a 40-mesh screen. Approximately 100 mg of sample was weighed, the exact amount recorded, and placed into 20-ml. Erlenmeyer flasks. Five ml. of distilled water was added to each flask. The flasks were then immersed in boiling water bath for 10 min. After cooling, 1 ml. of 0.2 M acetate buffer (pH 4.5) was added to each flask, followed by 1 ml. of a solution containing bovine serum and 100 units of amyloglucosidase. The flasks were then incubated in a shaking water bath at 45 C° for 48 hr. Following incubation, the contents were filtered, diluted (1:100) and 0.2 ml. of this dilution was the test sample, and one ml. of alkaline reagent was added to each test tube. All tubes were placed in a boiling water bath for 20 min and allowed to cool. One milliliter of arsenomolybdate reagent was added to each tube, for color development. Glucose standards were used to calibrate a Spec 20 spectrophotometer and sample absorbance was read at 540 nm.

Leaf Tissue Nitrogen

Two Y leaves (the most fully-expanded leaf at panicle initiation) were collected at random, from all plots in the 1984 and 1985 main crops. Two flag leaves were collected randomly from all return plots at heading (8) in both growing seasons. Leaf tissue was dried at 45 C° for approximately 48 hr, and ground in a Wiley mill with a 40-mesh screen. Exactly 100 mg of each sample and a plant standard were weighed and placed in test tubes. To each test tube was added 1.5 gm. of prepared catalyst (K₂SO₄ powder containing potassium nitrate, copper sulfate, and lithium). A blank was included in the testing. Four ml. of concentrated sulfuric acid

was added to the samples and digested for 3 hr. After the temperature reached 225 C° glass funnels were placed in each tube. The sample test tubes were removed from the digestion block and cooled for 30 min. The solutions were transferred to clean 50 ml. volumetric flasks and brought to volume with deionized water. Samples were assayed and a 2.1 ml. aliquot from each sample was added to a clean test tube. Then 2.5 ml. of buffer solution and 1.0 ml. of sodium molybdate/nitroprusside were added to each tube and vortexed. One ml. of sodium hypochlorite was added to each sample tube and vortexed. Samples were then diluted with 5.0 ml. of deionized water and held for use in for color development.

This leaf N determination is based on a colorimetric method in which an orange-green color is formed by the reaction of ammonia, sodium molybdate, sodium nitroprusside, and sodium hypochlorite in a buffered alkaline solution (Cataldo et al., 1974). Ammonia nitrogen standards were used to calibrate a Shim DZ spectrophotometer and sample absorbance was read at 630 nm.

Calculation and Statistical Analysis

The ratio of stem, leaf, and particle dry weights to total subsample dry weight was used to determine total sample dry weights for these plant components. Dry weight values were then divided by the total sample area to determine the weight of stems, leaves, and particles per square meter. Leaf area was measured on all subsamples. A ratio of subsample leaf weight/total sample leaf weight was calculated to determine leaf area for the total sample on a 1 m² basis. Crop growth rate was determined from the slope of the linear phase of total weight plotted against time. Particle growth rate was determined from the slope of the linear phase of particle

weight plotted against time. Both the crop growth and panicle growth curves were sigmoidal in shape displaying logarithmic, linear, and senescent growth stages over time. It was the linear portions of these curves that corresponded to respective growth rates. The linear portion of the crop growth curve corresponded to 14 to 36 d after harvest. The linear portion of the panicle growth curve corresponded to 42 to 77 d after harvest. Grain fitting period was determined as the effective grain fitting period (EGFP). EGFP was obtained by dividing the final grain (panicle) weight w^0 by the grain (panicle) growth rate. In 1988 and 1989, data were analyzed for both differences between cultivars and 8 treatments. Analysis of variance and regression analysis using a general linear model and correlations were calculated when appropriate using PC 3 & 5. (SAS Software, 1988).

RESULTS AND DISCUSSION

Climatological Data

Climatological data on temperature (measured in Bartow, FL) for the 1988 and 1989 growing seasons were extracted from publications of the National Science and Atmospheric Administration (NSAA). Solar radiation data were from the Agricultural Research and Educational Center at DRE, FL located approximately 40 km northwest of the Aprisa site.

Maximum, minimum, and mean temperatures for the 1988 and 1989 growing seasons are shown in Figure 1. The average minimum temperatures for the first three weeks of the 1988 and 1989 seasons were 14.7 °C and 18 °C, respectively. Seedlings in the 1988 main crop were slow to emerge probably due to both low temperatures and excessive planting depth and top soil crusting. Padilla (1978) stated temperatures of 18-40 °C as the optimum for rice germination and 25-30 °C as the optimum for rice emergence and establishment. For the first 12 weeks of the 1988 season and the first 8 weeks of the 1989 season the average temperature means were 19.4 °C for both years. In 1988, from week 9 to week 29 (a 21 week period), the average mean temperature was 26 °C. In 1989 from week 13 to 27 (a 15 week period) the average mean was 26.1 °C. Warmer temperatures (28 °C) started earlier and lasted longer in 1989 than in 1988. The thirteenth and last week of the 1989 return crop season cooled to a weekly mean of 18 °C. The last 4 weeks of the 1988 return crop season cooled to a weekly mean of

22.5 °C. The main crop and rotation crop combined growing seasons were 30.9 weeks (216 d) in 1988 and 38.2 weeks (270 d) in 1989.

Solar radiation data are shown in Fig. 2. Early season solar radiation values were low (40-80 MJ m⁻²) but after 3 weeks climbed to 140-180 MJ m⁻² and remained at that level until harvest in 1988. In 1989, solar radiation values were 140-200 MJ m⁻² for most of the growing season until week 28. In early to mid November, solar radiation values declined to below 100 MJ m⁻². In rice-growing areas of south Louisiana (Lat. 30 °N), monthly solar radiation means for April through October are higher than measured values in the 1988 and 1989 growing seasons in Series 71. (Lat. 29 °N). In southern Louisiana mean solar radiation values ranged from 200 MJ m⁻² in April to a high of 250 MJ m⁻² in June decreasing to 150 MJ m⁻² in October (U.S. Dept of Commerce, 1994).

Effects of Nitrogen Levels on Main-Crop Rice

Main-Crop Yield

There is a direct relationship between plant nutrient content and growth or yield of a plant. Smith (1982) stated that at low nutrient level yield was low. Growth increased when the nutrient content decreased slightly due to dilution caused by the higher production of plant material. In the next stage, growth rate is improved without any significant change in nutrient content. Then as nutrient content is increased the growth rate and nutrient content increased to a so called 'critical' level. Further increases in nutrient availability do not significantly increase growth rate and eventually nutrient levels reach toxic levels to the plant.

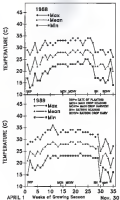


Fig. 3. Worldly maximum, mean, and minimum temperatures. For Review, FY, in 1980 and 1981 (over 10 months).

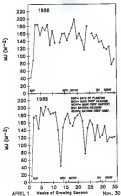


Fig. 2 Weekly solar radiation means from NOAA data, Ft. in the 1988 and 1989 growing seasons

T-leaf (the most recent, fully-expanded leaf of P1) was analysed for total N content in the 1988 and 1989 growing seasons. In Table 1, the ANOVA for the 1988 T-leaf displayed a N effect at the 5-0.05 level. Branson et al. (1991), in Louisiana, developed estimates of 'critical' and 'adequate-optimum' T-leaf N concentrations for 'Lafayette' and 'Balfour' (a seedling similar to Balfour). They found critical T-leaf N levels to be 25 and 33 mg N g⁻¹ leaf dry weight (dw) for Lafayette and Balfour, respectively. 'Adequate optimum' T-leaf N level ranges were 27 to 29 and 35 to 38 mg N for Lafayette and Balfour, respectively. 'Critical' level is defined as the point at which percent T-leaf N is associated with a 10% grain yield reduction below maximum yield. 'Adequate-optimum' T-leaf N levels are generally needed to achieve maximum yields.

In Table 2, the N content of the 1988 T-leaf increased linearly as N rates increased, for both cultivars. At the higher N rates of 150-200 kg N ha⁻¹ Balfour, a high N response seedling cultivar, approached critical and optimum T-leaf N levels. Lafayette, a low N response cultivar which performs adequately at lower N rates than seedlings, reached its critical and optimum T-leaf N levels at lower N rates of 50-100 kg N ha⁻¹ in 1988. Main crop yields (RCY) were analysed separately over years due to significant year interactions. Table 3.

RCY had a significant N effect in 1988. Table 4. In Table 5 the RCY data are represented by a linear regression equation over both cultivars. It is important to note that T-leaf N content also increased with increasing N rates in 1988. Branson et al. (1991) obtained similar T-leaf N values, to the values in this study, for Lafayette and Balfour. Branson

Table 3. *F* test, significance from combined ANOVA for yield and growth parameters of oilseed and linseed in response to 4 rates of phosphatic clay at lignite sites, Ball County, Iowa for growing seasons

treatm.	oil		linseed		crp		total		crp		growth		seed/straw		treatm.
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
Year (Y)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Location (L)	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
Y x L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Phosphorus (P)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Y x P	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
L x P	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Y x L x P	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rep (R) (error)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
D.F.	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15

1 = no difference at 5% level

2 = difference at 5% level

3 = difference at 1% level

4 = difference at 0.1% level

5 = not significant

Table 2. continued

Sample	Cells (n)	Bait crop (n)	Bait crop (n)	Bait crop (n)	Bait crop (n)	Bait crop (n)	Bait crop (n)	Bait crop (n)	Bait crop (n)
Year (Y)	1	10	1	1	1	1	1	1	1
Cultivar (C)	1	1	1	1	1	1	1	1	1
Y x C	10	10	10	10	10	10	10	10	10
Strawage (S)	1	1	1	1	1	1	1	1	1
Y x S	10	10	10	10	10	10	10	10	10
C x S	10	10	10	10	10	10	10	10	10
Rep (R) (times)	1	1	1	1	1	1	1	1	1
CR	14	41	21	21	21	21	21	21	21

1 = significance at $p < 0.05$ 2 = significance at $p < 0.01$ 3 = significance at $p < 0.001$

NS = Not significant

Table 4. Total nitrogen from August to April for each crop yield (RCY) minus crop yield (RCY) and total grain (RC + RCY) for Kentucky and Maryland in response to a total no phosphorus shift in April 1990, from County, 1989 and 1990 growing seasons.

Source	N	1989			1990		
		RCY	RC	Tot. N	RCY	RC	Tot. N
Culture (C)	1	85	85	85	1	85	*
Nitrogen (N)	4	+	85	+	+	+	+
C + N	4	85	85	85	85	+	85
Soil	1142 ^a	85	85	85	85	+	85
Q ^b		34	34	34	11	11	0

a = (1989) and 34 = 34 + 0.85

b = (1989) and 34 = 34 + 0.85

85 = 85 + 0.85

q = 0.85 for 1989 to 1990

Table 5. Main crop yield (Mg) of barleymeal (B) and Lentenest (L) in response to N rates on phosphatic soils at Agrius site, Fife County, for the 1988 and 1989 growing seasons.

Year	Cultivar	$\bar{X}$	Regression Eq.	r^2
1988	B and L	3558	$MY = 3558 + 71x$ SE 487 3	48
1989	B	3558	$MY = 3571 + 13.4x$ SE 375 1.7	45
	L	4458	$MY = 3558 + 71x$ SE 487 1.2	42

The LSD values at 5% probability level for comparing different means at the same N rate level: $MY (1988) = 874 \text{ kg ha}^{-1}$, $MY (1989) = 554 \text{ kg ha}^{-1}$.

noted that Labenmet's maximum yield was 1440 kg ha⁻¹ when 20 kg N ha⁻¹ was applied. Sulfmont produced a maximum yield of 1620 kg ha⁻¹ when 100 kg N ha⁻¹ was applied. Yields in Draden's study were 1700 kg ha⁻¹ higher than yields obtained in this study. Yield reductions were probably due to poor crop stands, resulting in low plant populations mostly caused by cool temperatures and poor water management during germination and emergence.

It is possible that due to low plant population in 1988 individual plants absorbed more applied N resulting in higher T-leaf N values than if a proper plant population had existed (0.290 plants m⁻²). The result would be T-leaf N values in the adequate to optimum range and depressed yields as was the case in the 1989 growing season.

The 1988 T-leaf N values are shown in Table 2 were 20 to 32 mg N lower than in 1989. This crop T-leaf had a response to N at the P=0.05 level, Table 1. T-leaf N values shown in 1989 had a classic quadratic response as described by Smith (1982) earlier in this paper. A possible explanation for the reduced T-leaf N in 1988 could relate to the T & delayed permanent flood after N treatments were applied. This delay could have resulted in N loss via denitrification and therefore low T-leaf N values; Labenmet, however did achieve its critical T-leaf N level of 20 mg N at the 500 kg N ha⁻¹ rate.

The 1988 RCY data showed a cultivar and N effect at the P=0.05 level, Table 4. Both Sulfmont and Labenmet grain yields responded to a linear fashion to N rates and produced higher yields in 1988 than in 1989, Table 3. In 1989, Labenmet produced more grain than Sulfmont at every N rate except zero and the crop stage was nearly 100% complete in 1989. Better stands in 1989 were due to less frequent flooding of the paddy

prior to permanent flood resulting in less soil crusting problems and a better seeded seedbed. In spite of possible B loss from denitrification, Lakshmi achieved its critical N level N level at the 300 kg ha⁻¹ rate and yielded 4400 kg ha⁻¹. Lakshmi yielded 4400 kg ha⁻¹ at the 300 kg N ha⁻¹ rate, 100 kg ha⁻¹ less than Lakshmi, and never achieved higher than 30 kg N. Thus, the relatively low N response plant type like Lakshmi, yielded better in what actually was a low soil N environment, than a high N response cultivar (Jalpa) that needed relatively high available N to achieve maximum yields. The proper plant density is 1000 accounted for higher water crop yields yields than in 1988.

Water Crop Growth Parameters

The F test significance from the ANOVA for WCY components for 1988 and 1989 is shown in Table 4 and 5, respectively. In Tables 7 and 8 are shown yield component means for 1988 and 1989, respectively. In 1988, partition n² (P0) showed a response to N at the P=0.05 level. In 1989 P0 showed a significant cultivar and N effect at the P=0.05 level. The linear regression equations for P0 are shown in Tables 7 and 8 for 1988 and 1989, respectively. In a direct-seeded system, P0 is equal to the number of seedlings or germinating tillers. Maximum tiller numbers (and P0 to a lesser extent) are primarily dependent on seeding rate. Analysis of variance was performed on combined tiller data over both seasons, Table 3. Both cultivar and N effects were significant for tiller number at the P=0.05 level, Table 10. It is well established that N application increases tillering in rice (Pogoda and Gbureck, 1981). The growth of the tiller is supported by the main culm until the three leaf stage, after which tiller leaf tissue begins photosynthetically (Sata, 1967). Therefore,

Table 4. F test significance from ANOVA for yield components of *Galbanus* and *Salsola* sown deep in response to N rates in plastic/plastic bags at Agris s/ha, Faha County, 1988 growing season.

Source	df	Residuals σ^2 ss	Straw μm^{-2} ss	1000 seeds wt. g	1000 spikelet g
Cultivar (C)	1	NS	NS	NS	NS
Nitrogen (N)	4	†	NS	NS	NS
C $\times$ N	4	NS	NS	NS	NS
Rep	2	NS	NS	NS	NS
CE		17	NS	4	8

† = significant at $p < 0.10$.

NS = Not significant.

Table 7. Yield components of main crop (for different N) and subsequent (1), in response to 8 rates of phosphatic class of legume straw, Baku County, 1988 growing season

Treatments	Grain yield, g/m ²	N-fertilizer (kg/ha)				N-fertilizer, kg/ha	Straw yield, g/m ²
		0	100	200	300	4	
Plants/m ²	6	100	100	100	100	100	60
	1	300	300	300	300	300	90
Grains per m ²	6	-	-	-	-	116	-
	1	-	-	-	-	120	-
1000 grains wt.	6	-	-	-	-	25.5	-
(g)	1	-	-	-	-	26.2	-
Harvest coefficient	6	-	-	-	-	60	-
g	1	-	-	-	-	67	-

The 100 values at 4-6% probability level for comparing values at the same N rates are: positive at² = 23, critical per² = 24, 1000-grain wt. = 2.2 g%, and % fitted coefficient = 33.

Table 2. F test significance from ANOVA for yield components of
 Gullfrost and Lakeland oats grown in response to 0 or 100 kg phosphate
 clays at Agrius site, York County, 1989 growing season.

Source	df	Particle μ^2 SS	Grain $\mu\text{m.}^2$ SS	1000 Grain wt. g	Filled spikelets %
Gullfrost (G)	1	+	+	NS	+
Lakeland (L)	1	+	NS	+	NS
G + L	1	NS	NS	NS	NS
Rep	4	NS	NS	NS	NS
CV		18	18	3	30

++ = highly significant at $p < 0.01$.

+ = significant at $p < 0.05$.

NS = Not significant.

Table 8. Yield component of main crop for Selfwerk (S) and Labernat (L) in response to N rates on phosphatic slays at Agrion 411a, Milk County, 1989 (growing 194100).

Yield Component	Selfwerk	$\bar{Y}$	Labernat	Regression Eq.	r^2
Panicles m^{-2}	S	111		$102 + 0.79x$ $95 \leq x \leq 0.33$	.91
	L	119		$102 + 0.79x$ $95 \leq x \leq 0.34$	.97
Grains gm^{-2}	S	85			
	L	78			
1000 Grains wt		28.1	S and L	$28 + 0.02x$ $17 \leq x \leq 0.20$	$0.99999x^2$ 0.99999
Filled spikelets $\%$	S	78			
	L	80			

The LSD values at 0.05 probability level for comparing means at the same N rate are: panicles m^{-2} = 11, grains gm^{-2} = 7, 1000 grains wt = 0.5 gm, and % Filled spikelets = 10.

Table 20: F test significance from ANOVA for main crop tiller number, leaf area index (LAI), and harvest index (HI) of Galbreath and Lakeland in response to N rates on phosphatic clay at Agricon site, Polk County over 2022 and 2023 growing seasons.

Source	DF	Tiller No.	LAI	HI
Galbreath (G)	1	1	1	1
Lakeland (L)	1	1	1	1
G * L	1	NS	NS	NS
Rep	4	NS	NS	NS
CG		20	41	8

* = significance at $\alpha = 0.05$

† = significance at $\alpha = 0.01$

NS = Not significant

LYNNING is closely associated with the nutritional condition of the soil cells, since a tiller receives carbohydrates and nutrients from the soil cells during its early growth. The linear regression equations for soil area tiller are given for each cultivar, Table 11. Low B response cultivars, The balanced tiller vigorously at moderate B rates and produce adequate LAI (Tusula, 1989). It is the author's speculation that in spite of the application of high B rates the actual available soil B was relatively low. Possible explanations for low available soil B could include desorption (especially in 1989), volatilization of ammonia resulting from neutral soil pH combined with high pH flocculation (caused by dense populations of carbon dioxide-absorbing algae), or direct algal excretion of inorganic B in competition with the plant water. Algae were present within and between crop rows in dense mats due to incomplete canopy cover. In such a low B soil environment a low B response cultivar would achieve its growth potential more fully than a high B response cultivar (Louisiana Cooperative Extension service, 1987).

Labadie's higher tiller number and LAI (which will be discussed later) may have been due to a differential in germination and emergence between Redford and Labadie. Jones (1985) noted in a variety trial on phosphatic clay soils, that sandier's soils to have less germination and emergence than tiller cultivars.

Grain particle² (GP), 1000 grain weight (GW), and percent filled cells (PFC) displayed no significant effects in 1988 as shown in Table 4. GP and PFC exhibited cultivar effects at the 5-40 B level, in 1989 (Table 4). Stress from low B at the critical period of spatula development can reduce GP (Rutagimana, 1989). Labadie, by absorbing B at

Table 11. Main crop tiller number of Galibank (G) and Lehmank (L) in response to N rates on phosphatic clay at Agriote site, Fife County, over 1988 and 1989 growing seasons.

Galliar	T	Regression Eq.	r ²
	tiller m ²		
G	242	$242 = \frac{168}{15} + \frac{0.016}{0.002}N$	.95
L	239	$239 = \frac{205}{15} + \frac{0.016}{0.002}N$	.95

The LSD value at 0.05 probability level for comparing means at the same N rate are: Tiller m² = 15

early FL, or a high rate of leaf 8 is reported to increase GP and decrease WU (Debetta, 1981). In this study 8 had no significant effect on GP or WU in either 1988 or 1989. G6, in 1988, showed a significant quadratic response to 8 index for both cultivars, Table 3. Grain weight showed no significant cultivar effect in either 1988 or 1989 and 8 had no effect in 1988. This non-significant 8 effect in 1988 for G6 is in accord with Sene and Kaurin (1987) who stated that G6 is a very stable varietal yield component in most situations.

In 1988, heading date was 102 days after planting and 82 d in 1989. This 20 d difference in heading date was likely due to the earlier onset and longer duration of warmer temperatures in 1988, Figure 1.

Average yields of Gulfsort and Labonnet were not significantly different in 1988 as shown in Table 4. Labonnet, in 1989, yielded more than Gulfsort by 445 kg ha⁻¹ rough rice. Labonnet had significantly more PR than Gulfsort due to its higher tiller number. A consequence of more PR is fewer GP which the data supported in Tables 7 and 8.

Leaf Area Index

Leaf crop LAI was measured at heading and analyzed combining both seasons, Table 3. Leaf area index had cultivar and 8 effects at the P=0.05 level, Table 10. Leaf area index has been noted by researchers to increase with decreased 8 rates (Fischer and Wilson 1976, Williams et al. 1984). Linear regression equations indicated Labonnet to have higher LAI over 8 rates than Gulfsort as shown in Table 12. Yoshida (1981) stated LAI is usually related to grain yield and that in semi-tender cultivars such as Gulfsort, 80% light interception (critical LAI) is achieved when LAI reaches 7.5. Labonnet, a drought-tolerant cultivar reaches critical LAI at

Table 12. Main crop leaf area index (LAI) and harvest index (HI) of fallow (F) and Lenten (L) in response to N rates in phosphatic clay at Apron Hill, Pella County, over 1988 and 1989 growing seasons

Cultivar		$\bar{X}$	Regression Eq.		r^2
Main Crop LAI	F	1.8	$y = LAI = 0.009 + 0.001x$ SE 0.17 2×10^{-4}		.55
	L	2.2	$y = LAI = 0.06 + 0.001x$ SE 0.10 2×10^{-4}		.87
Main Crop HI	F	68	$y = HI = 0.0001x$ SE 1.0 0.0002		.61
	L	64	$y = HI = 0.0001x$ SE 1.0 0.0002		.88

The LSD values at 0.05 probability level for comparing means at the same N rate are: Main Crop LAI = 0.8, main crop HI = 25.

approximately 3.7. The 1988 and 1989 seasons were combined, Table 3. At the 100 and 200 kg N ha⁻¹ rates Labenot had a greater LAI than 3.7, while Gelfond's LAI never exceeded 3.6. This further explains Labenot's higher RCT.

Grainward cultivars typically produce higher LAI than tiller cultivars at higher N rates. Yet in this study Gelfond produced lower LAI than Labenot at higher N rates. In 1988, plant density was low due to poor seed germination and emergence and tiller production. It is possible that Gelfond's germination and emergence were lower than Labenot's in 1988 as observed in a rice study on phosphoric sludge by Jones (1989). Labenot had significantly more tillers over both seasons and consequently higher LAI than Gelfond.

Harvest Index

Harvest index (HI), defined here as panicle weight w^2 divided by total crop weight w^1 as measured at main crop harvest (Delucia, 1991), is analyzed in Tables 1b and 1c. To obtain high grain yields, balanced growth at different growth stages must be attained. Balanced growth is reflected in the high ratio of panicle weight to total weight. Tall plants and extensive vegetative dry matter production reduce HI because carbohydrates are partitioned more into vegetative growth and less into seed production. The ANOVA for HI in Table 1b displayed cultivar and N effects at the 5-10-55 level. The main crop HI means and the linear regression equations are shown in Table 22. These equations show an inverse relationship between HI and N rate. As N rates increased panicle weight/total crop weight decreased. Tall cultivars are reported to show negative

correlations to RI (Yoshida, 1981). Due to increased plant height, and thus more vegetative growth, tall cultivars usually have lower RI than dwarfed cultivars as the regression equations show in Table 12.

Harvest index may have important implications for the ratoon crop if more carbohydrates are transported into grain production, less is likely to remain in the main crop stubble for ratoon tiller regeneration. In one study Cook and Yoshida (1982) exposed rice to radioactively-labeled carbon dioxide 18 d before flowering and traced the path of the labeled gas. In this study, 68% of the accumulated carbohydrates were translocated to the grain, 25% was respired, and 7% remained in the main crop stubble. Under adverse conditions, more stored carbohydrates may be used for grain filling with fewer carbohydrates left in the main crop stubble for subsequent ratoon growth.

Total Nonstructural Carbohydrates

Total nonstructural carbohydrates (TNC) of main crop stubble has been found to be positively and significantly correlated to several ratoon parameters (Jidiri and Scott, 1985). These include ratoon height, ratoon weight, and percentage of ratoon tillers relative to main crop tillers. They conclude that low main crop stubble carbohydrate levels may limit ratoon growth. In Table 13, TNC showed a β -effect at the $P=0.05$ level when both seasons were combined, Table 3. The negative linear regression equation and mean TNC values are shown in Table 14. This is consistent with the research of Yoshida and Abo (1988). They found that as N application increased, rice starch content was lowered. They hypothesized that N consumes some carbohydrates for synthesis of amino acids and

Table 10: F test significance from ANOVA for total nonstructural carbohydrate (TNC) of *Gutierrezia* and *Larrea* in response to 0-6 years of phosphorus inputs at Lytle's site, Pecos County over 1988 and 1989 growing seasons.

Source	DF	TNC
Cultivar (C)	1	NS
Phosphorus (P)	4	+
C * P	4	NS
Rep	2	NS
CE		NS

0 = (Significant) at $\alpha = 0.05$

NS = Not significant

Table 14. Total unhydrolyzed carbohydrates (TUC) of Cellulose (C) and Lignin (L) cells available for response to N rates as predicted by effect of N-fertilizer (100, 150 and 200 g/m²) and 2000 growing seasons.

Fertilizer	N applied (g/m ²)				N fertilizer application (g)	r ²
	50	100	150	200		
	TUC (mg/g dry wt.)					
C	190	204	187	180	104	$\frac{L}{C} \text{ TUC} = \frac{3.9}{0.1} = \frac{0.39 \text{ g/g}}{0.0001} = 39$
L	209	213	199	201	152	

For 100 g/m² of N 200 predicted dry TUC for comparing slopes of the lines is rate 100 = 10 mg/g dry wt.

partition and the formation of new organs (leaf blades and sheaths) requires much carbohydrate for cellulose, hemicellulose, and lignin.

There was a positive correlation in 1988, between TNC measured in main crop stubble and early rice panicle number m^{-2} measured at 14 and 28 GAE, Table 18. Subit and Sam (1989) reported a positive correlation between percentage of main tillers (% main tiller = number of main tillers/number of main crop tiller * 100) and starch content of the main culm. The analysis of TNC in 1988 displayed no significant main effects or interaction. The 1989 TNC analysis showed a collinear effect with late-maturing producing more main crop culm starch than tall-tillering. There were also numerically greater levels of TNC. In 1989 there was no significant correlation found between early rice panicle number and TNC. There is an clear explanation why a positive correlation was not found in 1988.

THE EFFECTS OF MAIN CROP SITUATION AFTER DRILLING DATE

Ratoon Crop Yield

Due to significant year interaction with tiller and R_0 , ratoon crop yields were analyzed separately by year, Table 3. The F test significance does the ANOVA for ratoon crop yield is shown in Table 4. In 1988 there were no significant effects or interactions and the coefficient of variation (CV) was 20 % for ratoon crop grain yield following the same trend established in the main crop grain yield CV of 14%. High CV's in 1988 were due to the highly variable plant population in main crop and consequently the ratoon crop also. Sam and Sam (1989) stated that in transplanted rice systems an acceptable range of CR for fertilizer trials is 10-120. This range of CR could be considered acceptable for direct-seeded system as well. Due to high CR in the 1988 study, data were of

Table 15. Correlation coefficients of rubisco titer (number at 14 and 28 days after harvesting [DAR]) vs total nonstructural carbohydrates [TNC] for Gulfport (G) and Loboson (L) in the 1988 and 1989 growing seasons

Variable	DAR	Cultivar	TNC	Year
Rubisco titer	14	G	0.49*	1988
ns, ns ²		L	0.64 ²	
	28	G	0.72 ²	
		L	0.62 ²	
Rubisco titer	14	G	0.24ns	1989
ns, ns ²		L	0.20ns	
	28	G	0.00ns	
		L	-0.05ns	

* = significant at $\alpha = 0.05$.

² = significant at $\alpha = 0.01$.

ns = not significant.

doubtful reliability. In 1988, the SE for maize crop grain yield, (Table 4) was 126, within the acceptable range. In 1989, plant population was highly variable resulting in high SE.

Nitrogen applied to a main crop and the subsequent effects on maize grain yield or N applied directly to the maize crop after main crop harvest have been investigated by several researchers (Mallin and Turner, 1988, Turner and McTigue, 1988, Swaden et al., 1989). These researchers suggest that addition of N to maize crop up to 112 kg ha^{-1} , when followed immediately with a plant, increased maize yields. Also, properly timed main crop N applications (at or around heading) increased maize yields. The yield data for maize crops in the 1988 and 1989 seasons are shown Table 18. In 1988, no significant differences existed between fallfrost and lateharvest grain yields. In 1989, however, a significant NPK interaction was reported, Table 4. In Table 18, the significant quadratic regression equation for lateharvest is shown. Lateharvest reached maximum yield at the 50 kg N ha^{-1} main crop N rate and produced 3550 kg ha^{-1} . Fallfrost showed no significant trends in response to main crop N rates. It is unclear as to why a yield response to main crop N rates appeared in the maize crop. The high probability of desiccification when the main crop was drilled for harvest would leave the maize crop N deficient. However, due to the extensive clay content of this soil it is possible that only three or four cm below the soil surface conditions were wet enough (anaerobic) to prevent desiccification. No significant difference was observed between cultivars averaged over 8 rates.

The maize crop grain yield as a percentage of main crop yield showed downward trends as N rates increased for lateharvest in 1988 and

Table 24. Net ion crop yield (NCR) of fullwood (S) and (aromatic L.) in response to S rates on phosphatic clayey at Agri-ice site, Palla County, for the 1988 and 1989 growing seasons.

Year	Sulfur rate (kg S/ha)	Net ion crop yield (kg/ha)					
		S	L	S	L	S	L
1988 NCR (kg S/ha)	5	340	340	1400	1400	3000	1440
	1	1100	2170	2120	2120	2410	2850
NCR at S	5	52	52	72	52	38	46
	1	50	78	61	43	42	46
1989 NCR (kg S/ha)	5	1610	1610	2030	2030	2320	2760
	1	3070	3030	3410	3030	3120	3120
NCR at S	5	129	129	94	94	58	80
	1	123	126	11	81	49	82

The 1988 values at 5 kg S/ha growing (top) represent the ion-crop yield values at the Luff's effect (S). Net ion crop yield (NCR) = (445 kg S/ha - maximum crop yield (1988) - 211 kg S/ha).

$$\text{NCR} = \frac{2040}{50} = 40.8 \text{ kg S/ha} \quad \text{at 5 kg S/ha}$$

Gulfport and Lohmead in 1988. In 1989, rubber crop grain yield percent of main crop grain yield was higher than 1988 due to complete crop stand in 1988.

Rubber Crop Growth Parameters

The main focus of this study was to investigate the effects of main crop nitrogen rates on rubber crop growth parameters. Rubber yield component AGR's per 1988 and 1989 are shown in Table 17. Grains per inch², GP, and SPI were found to have no significant B or C effects or interactions, in 1988. Particles m² showed only a cultivar effect at the P=0.05 level. Lohmead produced 180 PM and Gulfport produced 183 PM averaged over 8 rates. Lohmead produced more PM in the 1988 rubber crop due to higher main crop tillers in 1988, relative to Gulfport. Grains per inch², GP and SPI averaged 33, 26 g, and PM, respectively averaged over cultivars in 1988. In Table 18 the AGRs for rubber tiller numbers is shown. Rubber tiller numbers were analyzed separately by year and were measured at rubber harvest. Cultivars responded differently at the P=0.05 level. Lohmead generated 224 and 417 tiller m² compared to 180 and 182 for Gulfport in 1988 and 1989, respectively. As mentioned earlier, high variability in plant population in 1988 decreased the sensitivity of statistical tests to main crop yield components and this trend continued in the 1988 rubber crop response.

In 1989 the AGRs for rubber yield components, Table 17 showed cultivar effects at the P=0.05 level for PM, GP, and GP. No B or C/B interactions were observed as in 1988 rubber crop. Studies performed in Texas by Turner and McVittick (1988) may lend support for the rubber results in this study. In their study, main crop 8 rates applied before

Table 17. F test significance from ANOVA for yield components of Balfout and Lakemont radish entries in response to date crop is made on plots/plots made at April 15th, Park County, 1988 and 1989 growing seasons

1988

Source	DF	Partial r^2 %	Grains per sq	1000 Grains wt. g	Filled spikelets %
Cellular (C)	1	*	NS	NS	NS
Nitrogen (N)	4	NS	NS	NS	NS
C * N	4	NS	NS	NS	NS
Rep	2	NS	NS	NS	NS
DE		16	18	5	17

1989

Source	DF	Partial r^2 %	Grains per sq. ¹	1000 Grains wt. g	Filled spikelets %
Cellular (C)	1	†	†	†	NS
Nitrogen (N)	4	NS	NS	NS	NS
C * N	4	NS	NS	NS	NS
Rep	4	NS	NS	†	NS
DE		15	18	2	8

* = significant at $\alpha < 0.05$.

† = significant at $\alpha < 0.10$.

NS = Not significant.

Table 18. F test significance from ANOVA for cotton yield number at harvest of Gulfport and Lakeland in response to 0 rates of phosphoric class at Apalachee site, Polk County for 1999 and 2000 growing seasons

Treatment	DF	Yield No. 1999	Yield No. 2000
Gulfport LC	3	*	*
Lakeland (R)	4	NS	NS
L = R	4	NS	NS
Rep	2(1) ¹	NS	NS
LS		29	34

* = Significant at or < 0.05.

NS = Not significant.

¹ = df for rep in 2000

late crop heading had an effect on mature yields which would likely be reflected in mature plant components.

Plant component means for 1989 are shown in Table 10. The significance difference between cultivar PB is logical due to Labenat's higher main crop tiller number in 1989. In 1991 Labenat had significantly more mature tillers than Salinas averaged over 8 rates, which follows the main crop trend. Salinas had significantly more SP (30 vs 48) than Labenat and higher GR (22.4 vs 21.8 g). Comparative yield component advantages and disadvantages balanced out so cultivars showed no significant yield differences.

The graphs of tiller number over days after harvest are shown in Fig. 3 and 4. In Fig. 3, (1989), the general trend over time showed tillers to increase and reach maximum numbers at 30 days after harvest (DAH) for both cultivars. The quadratic regression equations of tiller number Y_L , DAH are shown in each graph. There was no discrimination, consistent trend between 8 rates over time. In Fig. 4, (1991), maximum tillering was reached earlier between 4E and 5E-8E for both cultivars. This is probably due to the 3 week earlier mature based 8 application in 1991. Maximum tiller number was reached at the 300 and 100 kg N ha⁻¹ rates in Salinas and Labenat, respectively. However, Salinas only produced approximately 450 tillers m⁻² at 300 kg N ha⁻¹ while Labenat produced approximately 580 tillers m⁻² at 100 kg N ha⁻¹.

Mature Plant Growth

Plant height was analyzed separately by season. In 1989, Fig. 5, both cultivars grew to height at fairly constant rates. The quadratic regression equations of plant height vs DAH are displayed in each graph.

Table 15. Autumn Crop yield components of Salswood (S) and Leobrook (L) in response to 8 rates of phosphatic dress at Agries 575a, 1933 County, 1939 growing season.

Yield Components		
	T	
Panicles m ²	S	232
	L	206
Grains pan ⁻¹	S	60
	L	48
1000 Grain wt.	S	33.6
	L	23.8
Filled spikes/m ²	S	25
	L	1

The 1939 values at 8.25 productivity level for comparing means at two rates of rate per panicle: m² = 22, grains pan⁻¹ = 7, 1000 grain wt. = 33.6 g, and 1 filled spikelet = 0.85.

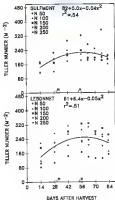


Fig. 3.— Mean values tiller number by H rate for Gulfbreeze and Lehigh at Apalachicola, Fl. in 1988.

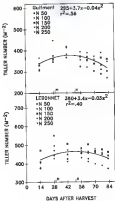


Fig. 4. Bean rot and tiller number by N rate for Gulfstream and Lebonnet at Agricut 111a, Polk County in 1983.

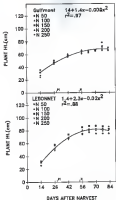


Fig. 3. Base versus plant height by N rate for Gullmead and Lebonnet at Agraria s.s., Ariz. County Co. 1988.

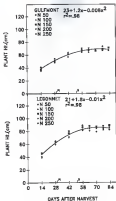


Fig. 4. Mean values of plant height by N rate for Sulphur and Leporel at Agricon 5116, Pott County in 1968.

Salween reached maximum height at 79 cm at 81 cm averaged over 3 replicates. Lohmaw reached maximum height at 83 cm at 81 cm averaged over 3 replicates. Analysis of variance showed plant heights to be different between cultivars at the $P=0.05$ level. Main crop 3 replicates had no significant effects on plant height throughout various development in 1988.

In 1989, (Fig. 4), plant height increase was constant up to 83 cm for Salween when maximum height was reached at 87 cm. Lohmaw achieved maximum height at 83 cm at 84 cm. The quadratic regression equations of plant height vs DMI are shown in each graph. Plant heights were different between cultivars at the $P=0.05$. No 3 effects were found for plant height over various development in 1989. No lodging was observed in either early or various crops in either year.

MINI-LEAF AREA INDEX

Increased tiller number and size of succulinate leaves resulted in increased LAI. Nitrogen has been found to increase LAI or weight of leaf blades (Morita, 1988). In this study, main crop basal 3 replicates did not significantly affect various tiller number, Table 18. According to Morita (1988) LAI reaches its highest value at 3-10 d before heading. Cultivars responded differently at the $P=0.05$ level and no 3 or interaction effects were observed. This may have been due to the high CP value (19%) representing the high variability in the data. Lohmaw and Salween achieved LAI's of 2.7 and 2.3, respectively. Lohmaw's higher LAI resulted from its higher tiller number. Lohmaw had higher LAI than Salween at the $P=0.05$ level. In Fig. 5 and 6 LAI is plotted and regressed over DMI with quadratic regression equations displayed in each

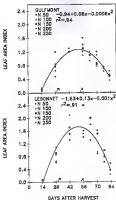


Fig. 2. Mean values leaf area index by M rate for Gulfmont and Lebonnet at Agraria sika, Pella County in 1988.

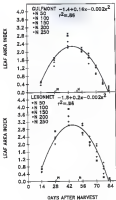


Fig. 8 Peak season leaf area index for N rate for Gulfmont and Lebonnet at Springville, Polk County in 1988.

graph. LAI peaked between 40 and 50 000 for both cultivars in 1988 and 1989.

Crop and Particle Growth Index

The growth curves for stem dry weights by N rates in 1988 and 1989 are shown in Figs 8 and 10, respectively. Stem weight increased up to 50 kg 000, shortly after heading in 1988 and 1989. Nitrogen rates of 150 and 200 kg N ha⁻¹ rates produced highest stem weights in Lakeland and Gullfonten, respectively. At these rates, Gullfonten yielded around 250 g m⁻² stem weight and Lakeland yielded about 340 g m⁻² stem weights. In 1989, the 150 and 200 kg N ha⁻¹ rates produced the highest stem weights in Gullfonten at about 300 g m⁻². The 50, 100, and 150 kg N ha⁻¹ rates produced the highest stem weights in Lakeland at approximately 300-450 g m⁻². The difference in stem mass from year to year is probably due to denser crop stands in 1988. Stem weight then generally decreased until 50 000 in both seasons. This decrease in stem weight suggests a redistribution of carbohydrates from stem to grain. Stems can serve as temporary storage organs and later redistribute their accumulated carbohydrates to panicles. Van Soest and Peterson (1982) reported that as much as 25% of the carbohydrates during grain filling came from previously stored carbohydrates. In this study Lakeland generally produced more stem weight m⁻² than Gullfonten due to its taller plant height. The percent loss of stem weight, defined here as maximum stem weight - final stem weight divided by maximum stem weight and multiplied by 100, was analyzed in both seasons. In 1988, no significant effects were found, but in 1989 a significant cultivar effect showed Gullfonten to have a 50% loss of stem weight compared to a 30% stem weight loss for Lakeland. Though values

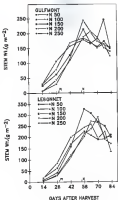


Fig. 2. Plant nitrogen stem dry weight by N rate for Gulfmont and Longmont at Arden site, Falls County in 1986.

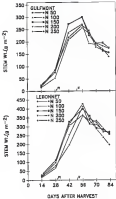


Fig. 30 Stem residue stem dry weight by N rate for Gulfmoet and Lebonnet at Apricot site, Polk County in 1989.

grain yields were not significantly different. Gulfmont 416 produced slightly higher grain yields, possibly due to greater distribution of tiller rice carbohydrates.

Leaf dry weight in 1966 reached maximum levels at 64 500 for 250, and 160 kg N ha⁻¹ rates for Gulfmont and Lebanon, respectively. The 50 and 100 kg N ha⁻¹ rates reached maximum levels at 48 500. Fig. 11. Gulfmont produced numerically greater leaf weight m² at the 250 kg N ha⁻¹ rate. Lebanon produced numerically greater leaf weight m² at the 160 kg N ha⁻¹ rate in 1966. Maximum leaf weights were reached at 48 500 for all N rates and both cultivars in 1965. Fig. 12. Gulfmont and Lebanon produced numerically greater leaf weight m² at the 200 and 160 kg N ha⁻¹ rates, respectively in 1965. After leaf weight in both seasons reached maximum levels, it declined to almost zero in 1965 and to between 20-30 g m⁻² in 1966. According to Naylor (1961) this decline in leaf weight is due to the death of lower leaves.

In Fig. 13 and 14, panicle weights m² are shown to follow a logistic function representing panicle growth from heading to maturity during 60 to 84 500. Panicle growth was initially slow, then entered a linear phase, and slowed or decreased at maturity. In 1966, wide fluctuations in panicle weight between N rates was most likely due to high stand variability. The 100, 200, and 300 kg N ha⁻¹ rates produced numerically higher final panicle weights for Gulfmont and these N rates generally produced the highest stem and leaf weights as well. The 100 and 160 kg N ha⁻¹ rates produced numerically higher final panicle weights for Lebanon and these N rates generally produced the higher stem and leaf weights. Leaf weight reached maximum level between 48-64 500 and stem weight reached maximum levels

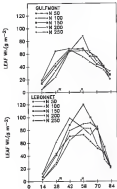


Fig. 11. Leaf dry weight by N rate for Gulfmont and Lebanon alfalfa at Apriceville, Polk County in 1968.

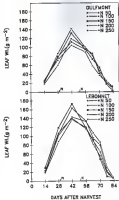


Fig. 12. Mean values leaf dry weight by harvest rate for Gulfmont and Lubbock at Agrico site, Pecos County in 1979.

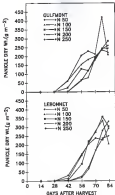


Fig. 10 Mean release particle dry weight by 6 nets for Gulfnet and Leachnet at depths 50m, 100m, 150m, 200m, 250m.

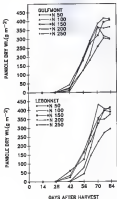


Fig. 14. Rese release particle dry weight by R rate for Gulfmont and Lebohmet at spruce sites, Park County in 1984.

between 50-60 DGS. These vegetative plant parts reached maximum weights shortly before or after heading and approximately 2 weeks after the start of the panicle linear growth phase.

In 1985, Fig. 14, considerably less fluctuation is seen between panicle weight growth curves due to less variable crop stand. Gullfjord reached the numerically greatest panicle weight m^2 at the 200 and 190 kg $N\ ha^{-1}$ rates. Final panicle weights in 1985 were higher over all N rates, for both cultivars, than in 1984. This was due to the higher plant population in 1985.

Panicle weight increases was constant despite typical loss of leaf area (LAI declined sharply between 40-60 DGS in both seasons), and stem weight. This may indicate that these sources of carbohydrates may have been important in grain filling.

Total dry weight graphs are shown in Fig. 15 and 16 and include the sum of leaf, stem, and panicle dry weights plotted over the relative growth cycle. These growth curves are referred to as a sigmoid growth curve which includes a logarithmic, linear, and asymptotic phase. The logarithmic phase occurred during the first 20 DGS in which plant size increased exponentially with time. The growth rate was initially slow, but increased quickly. The linear phase was generally between 20 to 35 DGS. This linear portion of the graph corresponds to the crop growth rate. The next phase is characterized by a declining growth rate, the asymptotic phase. Final total dry weights were higher over all N rates for Gullfjord and Lakeland in 1985 than in 1984.

Careful observation of the stem, leaf, panicle, and total weights m^2 plotted over DGS revealed a trend over cultivars and growing seasons.

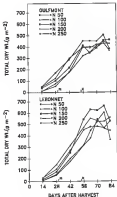


Fig. 25. Root system total dry weight by N rate for Oulmet and Leromet at Agrico siles, Pula County in 1988.

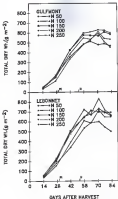


Fig. 16. Mean values total dry weight by H rate for Gullfrott and Leckonnet at Agrico s.r.l., Pella County in 1989.

Higher R rates resulted in a growth lag of all plant parts over the mature crop during. There is no other explanation for this trend.

Panicle growth rate data showed no significant effects in 1988. Crop growth rate exhibited both cultivar and R effects at the P=0.05 in 1988. Table 20. The quadratic regression equations for Gulfstream and Labonet in 1988 are shown in Table 21. This increase and decrease trend of CGR as R rates increased is due to the variable stands in 1988. The high CV (300) for CGR suggests high variability in the data and thus less sensitivity, via ANOVA analysis, to detect any significance. The CGR and PGR for 1988 are shown in Table 22.

In 1989 the CGR and PGR showed an C×R interaction at the P=0.05, Table 20. Labonet had a significant CGR response to R while Gulfstream showed no trend with R, Table 21. Labonet's regression equation shows a slight decrease in CGR as R rates increase. This is the opposite of what would be expected. Perhaps the higher R rates, which lowered TAC in main crop trials for both cultivars, affected the CGR of Labonet in a negative direction at the 250 kg R ha⁻¹ rate. PGR regression equations are shown in Table 21. Gulfstream had a slight positive linear response as R rates increased in 1989. Labonet's PGR showed a quadratic response to R rates. The CGR and PGR in 1989 are shown in Table 22. Note Labonet reached maximum PGR at the 250 kg R ha⁻¹ rate with a PGR of 13.62 g m⁻² d. Effective Grain Filling Period

Effective grain filling period (EGFP) was determined by dividing final panicle dry weight, measured at mature harvest, by panicle growth rate measured as the slope of the linear portion of panicle growth plotted over the ripening stage. Effective grain filling period was analyzed

Table 20. F test significance from ANOVA for various crop growth rate (CGR) and genetic growth rate (PGR) at Gulfport and Leland in response to N rates on phosphatic clay at Agrice site, Polk County, 1988 and 1989 growing seasons.

Source	1988			1989	
	DF	CGR	PGR	CGR	PGR
Cultivar (C)	1	*	NS	*	NS
Nitrogen (N)	4	*	NS	NS	*
C × N	4	NS	NS	*	*
Rep	2(4) ¹	*	*	NS	NS
CE		16	12	17	21

* = significance at or < 0.05

† = significance at or < 0.01

NS = NS significant

¹ = df for rep in 1989

Table 21. Regression equations for regions crop growth rate (CGR) and particle growth rate (PGR) for Softwood and Loblolly, in response to 8 total exogenous inputs at asymptotic stage of development. PGR twenty first and 1980 growing seasons

Year	Equation	CGR equation	r ²
1980	Softwood	$SG: 1.8 + 0.003x_1 + 0.000001x_2^2$ $SQ: 1.8 + 0.003x_1 + 0.000001x_2^2$	.86
	Loblolly	$SG: 1.8 + 0.003x_1 + 0.000001x_2^2$ $SQ: 1.8 + 0.003x_1 + 0.000001x_2^2$	.86
1981	Loblolly	$SG: 1.8 + 0.003x_1 + 0.000001x_2^2$ $SQ: 1.8 + 0.003x_1 + 0.000001x_2^2$	.89
	Softwood	$SG: 1.8 + 0.003x_1 + 0.000001x_2^2$ $SQ: 1.8 + 0.003x_1 + 0.000001x_2^2$	
	Softwood	$CGR: 1.8 + 0.003x_1 + 0.000001x_2^2$ $SQ: 1.8 + 0.003x_1 + 0.000001x_2^2$	.89
	Loblolly	$CGR: 1.8 + 0.003x_1 + 0.000001x_2^2$ $SQ: 1.8 + 0.003x_1 + 0.000001x_2^2$	.89

Table 10. 1966 Italian crop growth rate (CGR) and partition growth rate (PGR) of Lebanon and Galfranca at different N rates.

N Rates	Breath rates (mg/m ² /h)	CGR	PGR	Periods of linear growth	
		g 10 ⁻³ d		Days after harvest	
50	CGR	10.10	66	70	14-44
	PGR	7.70	1.21	70	42-70
100	CGR	10.63	1.24	68	14-44
	PGR	9.83	1.40	71	42-70
150	CGR	10.86	1.40	71	14-44
	PGR	9.56	1.34	68	42-70
200	CGR	7.48	1.25	75	14-44
	PGR	9.43	1.36	67	42-70
250	CGR	8.88	82	66	14-44
	PGR	7.64	1.31	66	42-70
Galfranca					
50	CGR	9.42	70	66	14-44
	PGR	8.24	1.61	66	42-70
100	CGR	9.79	1.73	65	14-44
	PGR	9.42	1.82	65	42-70
150	CGR	9.79	1.81	70	14-44
	PGR	9.24	1.73	68	42-70
200	CGR	7.91	64	74	14-44
	PGR	6.76	64	70	42-70
250	CGR	9.95	1.83	67	14-44
	PGR	8.48	67	62	42-70

Table 22. 1989 lettuce crop growth rate (CGR) and rootlet growth rate (RGR) of Lebanon and Redhead at different N rates.

N rates	Breeds	Lebanon	S. L.	P ²	Periods of linear growth
					(days after harvest)
		g m ⁻² d			
50	CGR	18.89	1.58	.88	14-16
	RGR	18.35	1.12	.79	45-77
100	CGR	18.35	.79	.95	14-16
	RGR	18.42	1.45	.79	45-77
150	CGR	14.29	.79	.15	14-16
	RGR	11.81	.18	.45	45-77
200	CGR	13.91	.38	.14	14-16
	RGR	11.81	1.58	.88	45-77
250	CGR	11.45	.48	.04	14-16
	RGR	8.34	.54	.78	45-77
Redhead					
50	CGR	16.74	1.58	.78	14-16
	RGR	8.15	.88	.88	45-77
100	CGR	17.75	.79	.04	14-16
	RGR	11.45	1.12	.88	45-77
150	CGR	13.19	.38	.17	14-16
	RGR	15.44	.79	.88	45-77
200	CGR	11.54	1.58	.08	14-16
	RGR	12.38	1.37	.88	45-77
250	CGR	11.49	1.38	.01	14-16
	RGR	12.25	1.08	.08	45-77

separately by year, Table 3. No significant effects or interactions were found for 1988, Table 3b. The GPP had a B effect in 1989 at the 0.05 level. The quadratic regression equation is shown in Table 2b. Effective grain filling period is mostly determined by temperature. High temperatures, greater than 30 °C, will shorten the GPP in sorghum and in Japanese rice to a degree that grain yields are reduced (Sale and Takahashi, 1970). The mean temperature of the warm grain ripening period was 23 °C and 24 ± 1 °C for 2000 and 2001, respectively. These temperatures are well within the optimum temperature range for ripening at 18 to 29 °C (Johanna, 1989). In Table 2b are shown GPP means for both cultivars. Galfenat and Labenat previously achieved high GPP (30 and 42 d, respectively) at various B rates, in 1988. It is the author's contention that these high GPP's are likely due to low grain's growth rate measurements resulting from poor crop stands in 1988.

Relative Harvest Index

The 1988 relative HI showed no significant B or C effects or interaction while the 1989 HI displayed a C×B interaction at the 0.05, Table 2c. The slightly positive linear regression equation for Galfenat is shown in Table 2c. Thus as B rates increased Galfenat's relative HI increased suggesting that Galfenat may have partitioned its available N and phosphorus more effectively into grain production. Galfenat had a significantly higher HI than Labenat.

Total Yields

Total yields are shown in Table 2d for 1988 and 1989 by B rates and cultivars. Analysis was done separately by year, Table 3. In 1988 yields increased over all B rates except Labenat at 250 kg B ha⁻¹ rate which was

Table 26. F test significance from ANOVA for effective growth (tilling period) (TGP) for Soil from 1 and 2000000, in response to 8 trials on phosphatic clays at Agrico site, Aika County For 1988 and 1989 growing seasons.

Source	DF	TGP (1988)	TGP (1989)
Cultivar (C)	1	NS	NS
Repurgen (R)	4	NS	*
C * R	4	NS	NS
Rep	1(4) [†]	†	NS
CV		28	31

* = significance at or < 0.05.

† = significance at or < 0.01.

NS = Not significant.

[†] = df is 1988.

Table 25. Effective-grain-filling period (EGFP) for Calhoun (C) and Calhoun2 (C₂) in response to R rates on phosphatic clay at Agricola site, Polk County, in 1989 and 1990 growing season

Year	Cultivar	T	Regression Eq.	r ²
1989	C and C ₂	28		
1990	C and C ₂	24	$28.8 + \frac{0.002x}{92.2 - x} = 0.002x + 0.000000x^2$ $0.008 \quad 3 \times 10^{-4}$	19

The LSD values at 5.0% probability level for comparing cultivar means at the same R rate were: EGFP (1989) = 8 d EGFP, EGFP (1990) = 6d

Table 26. F test significance from ANOVA for harvest index (HI) of Salinas and Tabasco potato crop in response to N rates on phosphate class at Apetla silt, Potosi County in 1988 and 1989 growing seasons.

Season	SE	HI (1988)	HI (1989)
Cultivar (C)	1	NS	†
Nitrogen (N)	4	NS	NS
C × N	4	NS	*
Rep	2 (C) †	NS	NS
CV		15	5

* = significance at or < 0.05

† = significance at or < 0.01

NS = Not significant

† = df in 1989

Table 23. Harvest Index (HI) of rajon crop in response to 8 rates of phosphate crops at Agrichirya, Palla County, in the 1986 and 1987 growing seasons.

Year	Cellulose	$\bar{X}$	Regression line	r^2
1986 (1986)	0 and 1	67		
1986 (1987)	0	48	$48 + 0.0001x$ at L.S. 0.0002	-27
	1	69		

The LSD values at 0.05 probability level for comparing cellulose means at the same 8 rate crop: Rajon crop L.S. = 8.4, rajon crop 00 (1986) = 88, rajon crop 01 (1987) = 76.

Table 10. Total yield means (bars = values $\pm$ s.e.d.) of full-season (F) and late-season (L) in response to B rates on phosphoric clays at Apricotville, Idaho County for two (200) and (2000) growing seasons

Year	B rate (lb/acre) applied Oct. 1st									
	0	20	40	60	80	100	120	140	160	180
2000 Total yield	6	3120	4120	4100	4100	4100	4100	4100	4100	4100
2000 F	1	1510	4110	4110	4110	4110	4110	4110	4110	4110
2000 L	5	1610	4010	4000	4000	4000	4000	4000	4000	4000
2000 Total yield	1	4730	8130	8130	8130	8130	8130	8130	8130	8130
2000 F	1	4000	8000	8000	8000	8000	8000	8000	8000	8000
2000 L	5	730	130	130	130	130	130	130	130	130

The (200) values at 0 lb applied (0 lb/acre) for comparing cellulosic means at the same B rate are: Total yield, (Total) = 4100 kg ha⁻¹; Total yield, (Total) = 160 kg ha⁻¹.

Highly due to sampling error and variable plant density. A linear regression equation represents Sulfenat and Labenat total yields in response to N. Mean grain yields, averaged over 8 rates, showed no significant difference between Sulfenat and Labenat.

In 1988 both Sulfenat and Labenat total grain yields increased over 8 rates to reach maximum yields at the 100 kg N ha⁻¹ rate. Fertilest linear regression equations are shown in Table III. Labenat yielded significantly more grain than Sulfenat averaged over 8 rates. This was an unexpected result. Sulfenat, a high N response oatland cultivar, typically produces more grain than Labenat, a relatively low N response cultivar (Jones, 1988; Laroche, 1980; Menden et al., 1989). The total yield of Sulfenat was adequate for Florida's conditions while total yield of Labenat was higher for Florida's conditions. No lodging was noticed in Labenat, a lodging susceptible cultivar.

Growth of Juvenile Crop Growth

Straw plant height data (Figs. 5 and 6) exhibited a steady increase in both years up to 90 GAI (about 1/2 after heading), after which plant height remained static. Maximum plant height (PH) at heading for Sulfenat and Labenat ratoon crops reached 75 and 65 cm, respectively. These PH are considered shorter than typical main crop PH reported for Sulfenat and Labenat which range from 85 to 95 cm for Sulfenat and 100 to 105 cm for Labenat (Laroche, 1980; Jones, 1988; LEO agronomic services, 1987). Maximum main crop PH at heading reached 95 and 85 cm for Labenat and Sulfenat, respectively. Shorter ratoon PH has been reported by Infante-Fernandez et al. (1984), and is probably due to the shorter vegetative phase of ratoon growth.

Main crop LAI for erect-leaved cultivars, such as Bulfinch, intercepts 90% of the sunlight at an LAI of 7.5, but Lakeland, a drooping-leaved cultivar, supposedly intercepts 90% of solar radiation at LAI of 5.7 (Pridmore, 1981). In this study the main crop LAI reached maximum levels at 3.5 for Bulfinch and 4.5 for Lakeland though in 2000 variable plant populations tended to lower the overall averages. Laroche (1987) reported main crop LAI's of 4.5 for Bulfinch and 5.7 for Lakeland. In both growing seasons (Fig. 7 and 8) LAI increased quickly from 30-50% after joint before or after heading (44-56 DGG), when maximum LAI was achieved. Leaf area index then sharply declined during the ripening phase. Minimum LAI's reached maximum levels in 2000 of 2.5 for Bulfinch and 3.0 for Lakeland. Lower minimum LAI may be due to the reduced vegetative period or reduced tiller number.

Main crop tiller number increased steadily over 8 weeks and achieved maximum values of 296 and 334 tillers m^{-2} for Bulfinch and Lakeland, respectively, over both growing seasons. Minimum crop tiller numbers, not affected by main crop 8 weeks, produced 236 and 316 m^{-2} tillers for Bulfinch and Lakeland, respectively. This represented a slight decrease of approximately 50 tillers m^{-2} and helps to explain the reduced minimum LAI. Lower minimum tiller number may usually be due to a shorter vegetative period or reduced TRC levels in main crop plants. Reduced TRC levels were observed as main crop 8 weeks increased. However, these minimum tiller numbers represented two year averages and 1998 plant populations were highly variable resulting in low main and minimum crop tiller numbers. In 2000 minimum tiller numbers were significantly greater than in 2000 for both cultivars.

Graphs of plant part dry weight accumulation, such as stem, leaf, and panicle weights are shown in Figures 8 through 14. Between stem and leaf weights for 1968 reached maximum weight at 38-43 GAE and 42-54 GAE, respectively. Heading date was 32 GAE. Stem and leaf weight attained maximum levels in 1969 at 58 and 48 GAE, respectively. Heading date was 38 GAE. The earlier maximum levels reached in 1969 were likely due to the three weeks earlier release & application than in 1968. Stem and leaf weight growth rates decreased at the beginning of grain growth and illustrated the determinate habit of retrans rice. Stem weight increased rapidly up to 38 GAE which corresponded to the early linear portion of the panicle growth curve in 1968. Stem weight decreased sharply from 38-78 GAE, after which stem weight decreased somewhat less rapidly to 84 GAE. This decrease in stem weight suggests a redistribution of carbohydrates from stem to grain. Stems may serve as temporary storage organ and redistribute carbohydrates to panicles (Pan Gai and Peterson, 1964). Laksoet generally had numerically higher stem weight than Sulfent in both seasons and Laksoet 79C data exhibited numerically higher values than Sulfent. Leaf dry matter increased rapidly to 42 GAE in 1968 at or around 71 (78 GAE in 1969 and 31 GAE in 1969) and then decreased rapidly to 84 GAE. Leaf dry matter decreased due to death of lower leaves (Yoshida, 1961).

Both crop stem and leaf dry matter data displayed different growth patterns than retrans crop trends. Both crop leaf and stem dry matter growth rates were slower, reached maximum levels later in the growing season, declined less rapidly, and reached stable, prolonged weights

(Quarles, 1987). The four to five weeks longer growing season of rain crop rice explains the more gradual dry matter development and decline.

Panicle dry weight graphs shown in Figures 13 and 14 represent panicle weight increase from heading (50% of panicles emerged from flag leaf sheath) to maturity. Grain growth rate was initially slow, entered a linear phase, and slowed toward maturity. The linear phase represents the grain filling period, during which most of the dry weight of the grain is obtained. Grain growth rate was constant despite loss of leaf and stem weight which indicates that both sources of assimilate were being used important in grain filling. Isukle (1981) and Nakamura (1976) noted that accumulated carbohydrates may contribute up to 40% of grain carbohydrates.

Total dry weight curves are represented in Figures 15 and 16. These graphs are the accumulated leaf, stem, and panicle (plus grasses) weights plotted over ricean ontogeny. Crop growth rate is obtained from the slope of the linear portion of each curve. Crop growth rates in the 1989 ricean crop were similar for both cultivars. In 1989 Labanan CGR decreased as R rates increased though it remained numerically higher, over most R rates, than delphin which had a stable CGR over R rates. This may be the result of a higher LAI obtained by Labanan. It was noted by Williams et al (1981) that CGR of a crop increased with increased LAI.

SUMMARY AND CONCLUSIONS

Phosphatic clay settling ponds in central Florida represent a potentially valuable resource for agricultural production. As phosphate mining in Polk and other counties closes down operations in the near future the economic impact would result in loss of jobs and tax revenues. Reclamation of settling pond clays for agricultural production could provide the opportunity for a new economic foundation for Polk and surrounding counties. Soil analysis and extensive agronomy, horticultural, and forestry experimental trials have demonstrated proven ability of a large variety of plant and crop species to grow and produce successfully on phosphatic clays.

In 1983, 1988, and 1989 paddy rice was grown at the Agrice site in Polk county to investigate 8 effects on main crop growth parameters and how these may have affected native crop performance. The 1987 study was not reported in this paper due to native crop failure caused by cold temperature induced pollen sterility. Date of planting (DOP) in 1987 was in late May resulting in native crop pollen reduction-division stage exposure to cool October temperatures. Thus, DOP in early to mid April is recommended for successful rice ratoon production in this area.

Data analysis of 1988 and 1989 studies generated the following results:

- (1) Planting depth and proper water management before emergence are critical to successful and complete stand establishment on phosphatic clays.

- (3) Total nonstructural carbohydrates, measured in main crop tubers, decreased as N rates increased. Significant and positive correlations were found between early season tiller number (at 14 and 28 DAP) and TNC concentration in 1988.
- (4) Main crop tiller number m^{-2} increased as N rates increased for both cultivars. Labenat produced more tillers than Galfrost. Season tiller data showed no N effect although Labenat produced more tillers m^{-2} than Galfrost.
- (5) LAI in main crop increased as N rates increased while season LAI did not respond to N rates. Labenat produced higher LAI than Galfrost over most N rates due to its higher tiller number m^{-2} .
- (6) Main crop particle m^{-3} (PM) increased as N rates increased with Labenat producing more particles than Galfrost. Season crop PM data exhibited no N effect and Labenat continued the trend producing more PM than Galfrost. In both main and season crops Galfrost produced more grain particle t^{-1} than Labenat. No N effects were noted in season crop yield components in either year.
- (7) Season ESP in 1988 had no N effect, but in 1989 ESP showed a quadratic response to N. Mean ESP, averaged over N rates, were 23 and 25 d for Galfrost and Labenat, respectively.
- (8) Variable plant density in 1988 resulted in variable yield data. In 1988 main crop yields of Labenat (1480 kg ha^{-1}) were greater ($P=0.01$) than Galfrost (1438 kg ha^{-1}). Season crop data displayed no N effect for Galfrost while Labenat

displayed a quadratic N response. Maximum release yields were 2300 kg ha⁻¹ for both cultivars, total yield data for both cultivars exhibited a linear N effect. Total yields of Lohmeyer were greater (24.4%) than Solheim (7790 kg; 7490 kg ha⁻¹, respectively).

It is clear that residual main crop N did not directly affect rutabaga crop growth parameters, but main crop parameters that displayed N effects did influence rutabaga crop performance. These findings suggest that proper main crop N fertility can produce acceptable main and rutabaga crop yields on phosphatic clay.

Future Research

This study has only begun to explore how N fertility management can be optimized for maximum main and rutabaga crop production. Further research studies might include:

- (1) Effects of main crop N placement (broadcast vs. incorporation).
- (2) Effects of N timing on main crop and subsequent effects on rutabaga crop.
- (3) N rate and timing study on rutabaga crop.
- (4) Planting depth and water management effects on germination and emergence.

Table A-1. Biom crop flag leaf tissue N analysis for fallow (0) and (reduced 11) N response for N values on phosphorus, clay in Agria area, Mesa County, for 1988 and 1989 growing seasons.

Year	Fertilizer	N rate, ppm N, available, lb/acre						Coefficient	Regression Eq.	r ²
		0	100	200	300	400	500			
..... mg g ⁻¹ dry wt.										
1988	0	26	34	25	23	34	34			
	1	28	31	26	34	36	36			
	6	29	32	26	37	38	37	6	$37 = 0.242x + 0.00002x^2$	58
	1	28	32	33	33	33	33	1	$36 = 0.0016x + 0.00002x^2$	48

The L20 values at 0.20 percent nitrogen level for comparing means at the same N rate area. 1988 Flag leaf 2 mg g⁻¹ dry wt, 1989 flag leaf 2 mg g⁻¹ dry wt.

Table A-2. Random crop flag leaf tissue N analysis for Bullhead (B) and Lakeland (L) in response to N rates on phosphatic soils at Agraria site, Fort Collins for 1998 and 1999 growing seasons

		Random crop flag leaf N (ppm, by %)					
Year	Cell Count	0	50	100	150	200	S.E.
mg g ⁻¹ dry wt							
1998	B	31	32	30	33	30	31
	L	26	30	27	26	29	23
1999	B	27	26	26	27	26	23
	L	22	22	22	22	22	22

The LSD values at 0.05 probability level for comparing means at the same N rate are: 1998 random flag leaf = 3 mg g⁻¹ dry wt, 1999 random flag leaf = 3 mg g⁻¹ dry wt

Table A-1. F test significance from ANOVA for main crop yield of *S. mitchellii* and *S. tuberosa* in response to 5 rates of phosphatic clay at Agrico 311a, Holt County in the 1987 growing season

Source	DF	Main Crop Yield
Calcium (C)	1	†
Nitrogen (N)	4	†
C × N	4	NS
Rep	4	†
CF		30

† = Significant at $\alpha = 0.05$

NS = Not significant.

Table 3.4. Mean crop yield (kg/ha), mean, and regression statistics of Sulphur (S) and Calcium (Ca) on response to S rates in phosphatic clay at Igarka village, Palla County in the 1982 growing season.

	S applied (kg/ha)					Regression eq.	r
	0	100	200	300	400		
	. Mean Rice (kg/ha)						
NCT	S	2050	4130	6020	6660	$MY = 2948 + 0.004 S - 0.000002 S^2$	0.92
	L	3440	4000	5440	6710	$MY = 3108 + 0.003 S - 0.000002 S^2$	0.71

The LSO values at 0.05 probability level for comparing means at the same S rate are: NCT = 193 kg/ha.

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BIOGRAPHICAL SKETCH

John Burke Evans, a bright and imaginative youth, was born in Los Angeles where he spent his first 17 years. He attended Loyola Marymount University, a Jesuit institution, and obtained a B.S. in Biology in 1979. After several years of working in various food-related industries he joined the Peace Corps/Alouatta. As an "engineer of appropriate technology" he worked in a farm energy program constructing a biogas digester. Upon his return he attended Arizona State University and received an M.S. degree in environmental resources in agriculture in 1983. In search of more technical training he attended the University of Florida and received a PhD in 1988. At present he has accepted a position as a maize and bean crop extensionist in Guatemala as a Peace Corps volunteer.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy


Gordon B. Jones, Chair
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy


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